Climate Change and Water Availability - A Civil Security Issue?

Harald Kunstmann

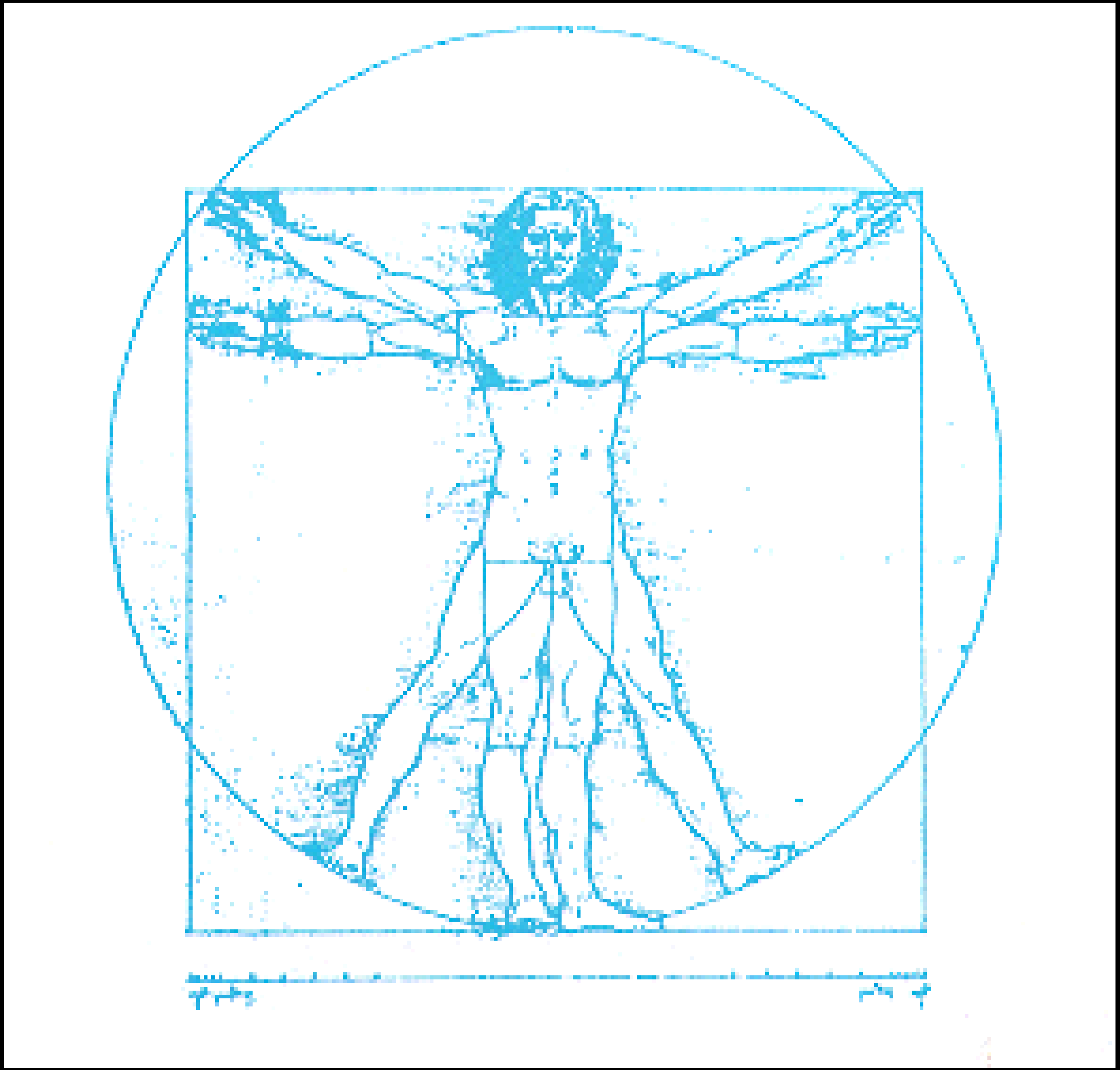
The Blue Planet

70% Ocean

30% Land

Not Enough Water?

The Human Being

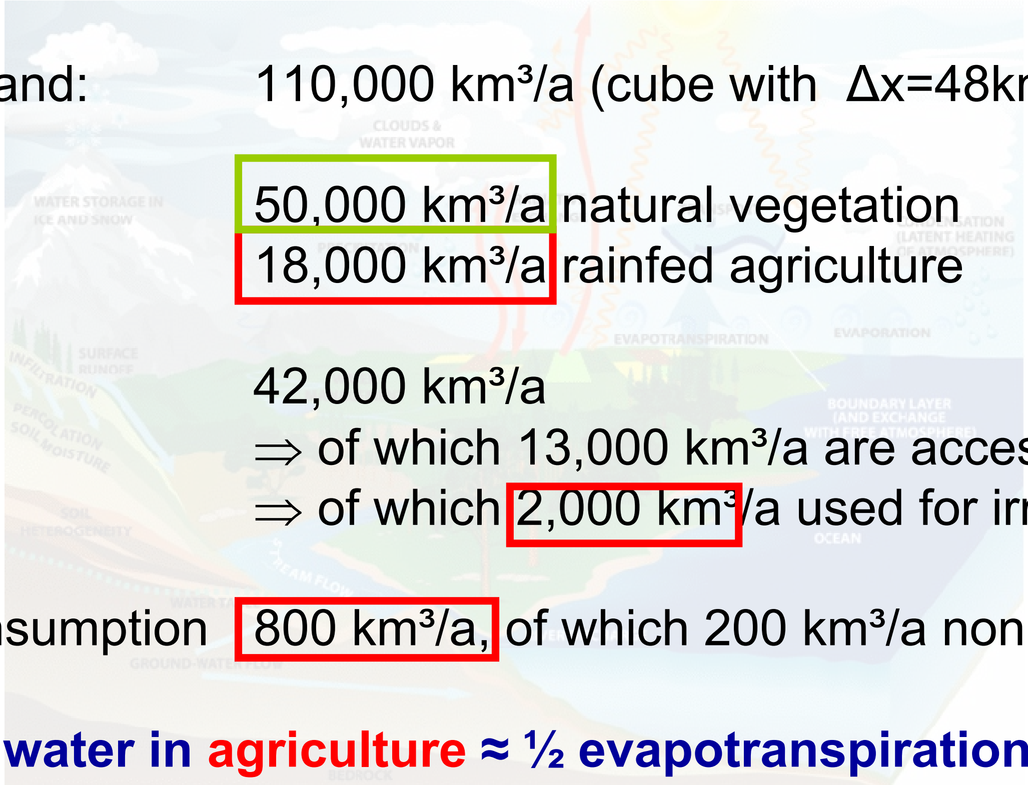


60-70% Water

Too Much Water?

Water Availability

Worldwater



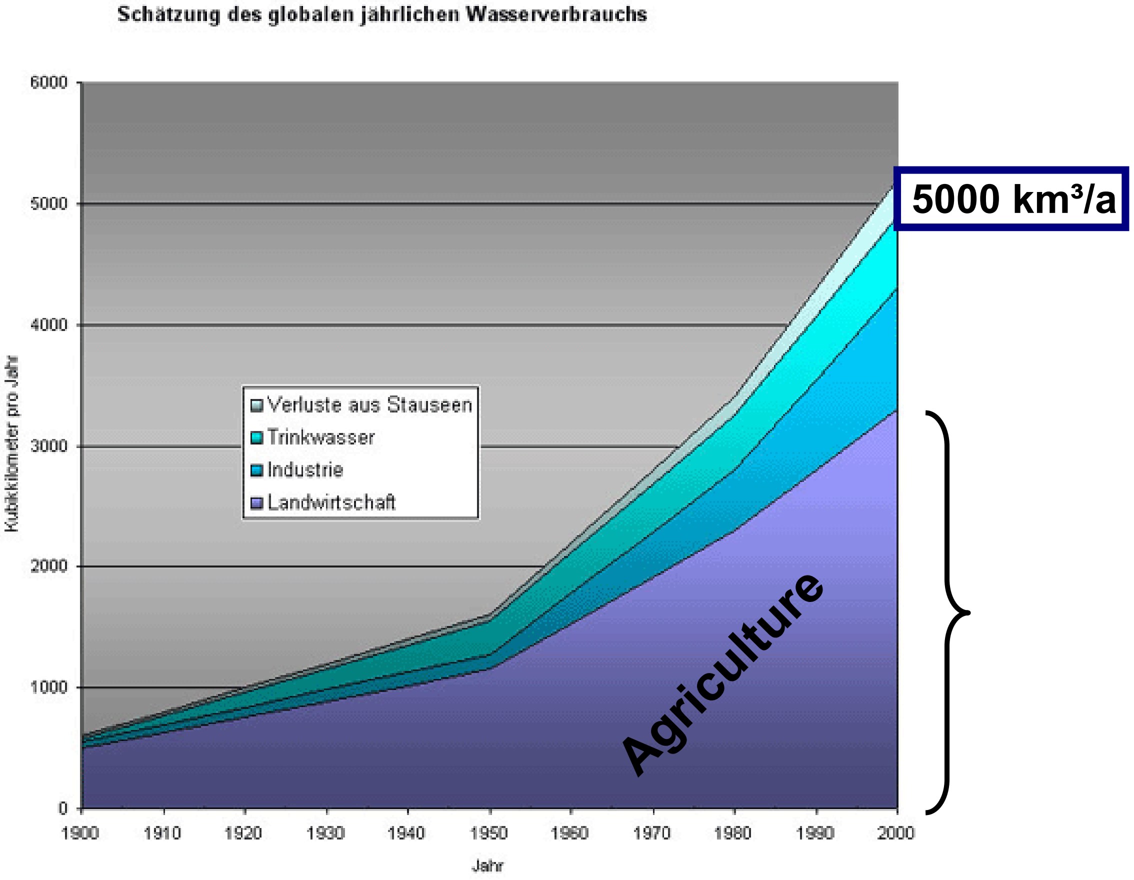
Precipitation on land:	110,000 km³/a (cube with Δx=48km)
Evaporation:	50,000 km³/a natural vegetation 18,000 km³/a rainfed agriculture
Rivers:	42,000 km³/a ⇒ of which 13,000 km³/a are accesible for human ⇒ of which 2,000 km³/a used for irrigation
Groundwater consumption	800 km³/a, of which 200 km³/a non sustainable

⇒ Evapotranspired water in agriculture ≈ ½ evapotranspiration of natural vegetation

Water Availability

Worldwater

Nutzbares Süsswasser: 9 - 12'000 km3 0.0009 %
(Würfel mit Kantenlänge 21.5 km)



Already ⅓ till ½ of global available freshwater resources are used!

Water Availability

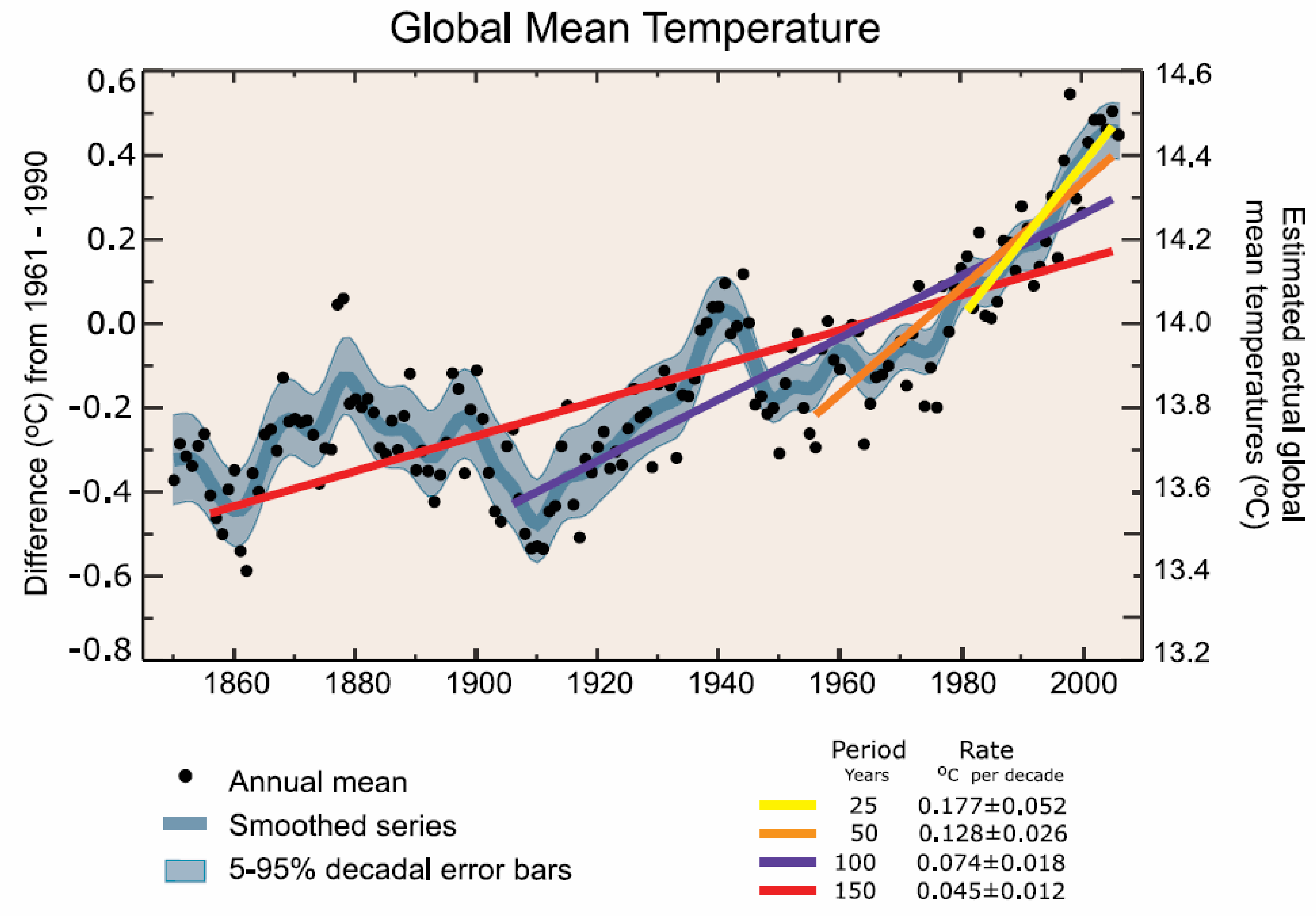
Humans affected by water scarcity
2004: 600 millions ⇔ 2025: 2.7-3.2 billion

Worsening of situation by amplified water consumption:
20. century: tripling of word population, but 6-fold increase of world water consumption

Climate Change
Induces
Additional Changes
in Future Water Availability

World population

Global Climate Change: Observations



IPCC, 4AR

Global Climate Change

12. Oktober 2007 Drucken | Senden | Leserbrief | Bookmark

OSLO Schrift: − +

Friedensnobelpreis für Al Gore und den Uno-Klimarat

Der diesjährige Friedensnobelpreis geht an den früheren US-Vizepräsidenten Al Gore und den Uno-Klimarat. Gore wurde für seinen Einsatz gegen eine drohende Klimakatastrophe ausgezeichnet.

Oslo - Höchste Auszeichnung für Al Gore und den Uno-Klimarat: In Oslo wurde dem ehemaligen US-Vizepräsidenten und der Organisation IPCC der Friedensnobelpreis zugesprochen. Der Chef des Nobelkomitees, Ole Danbolt Mjøs, sagte bei der Bekanntgabe: "Gore und der IPCC haben schon sehr früh die Gefahren der globalen Klimaänderung erkannt. Wir möchten mit unseren Entscheidung die Aufmerksamkeit für dieses Thema weiter erhöhen."

Water and Global Warming

Background

- Higher temperatures ⇒ increased evapotranspiration
- Warm air can carry more moisture ⇒ increased atmospheric water content
- latent heat of evaporation ⇒ increased atmospheric energy content

⇒ Intensification of water cycle

Impacts

- Changes in rainfall intensities
- Changes in spatial and temporal distribution of rainfall

⇒ Increased flooding risks but also drought risks

Global Climate Change: Regional Consequences

Hochwasser-ereignis	*Total (Mio. €)*	*Versichert (Mio. €)*
Bayern 1999	**393**	**30**
Bayern 2005	**205**	**46**
D/A/CH 1999	**409**	**40**
D/A/CH 2005	**3000**	**1700**

Floods in the Alpine Space

Global Climate Change: Regional Consequences

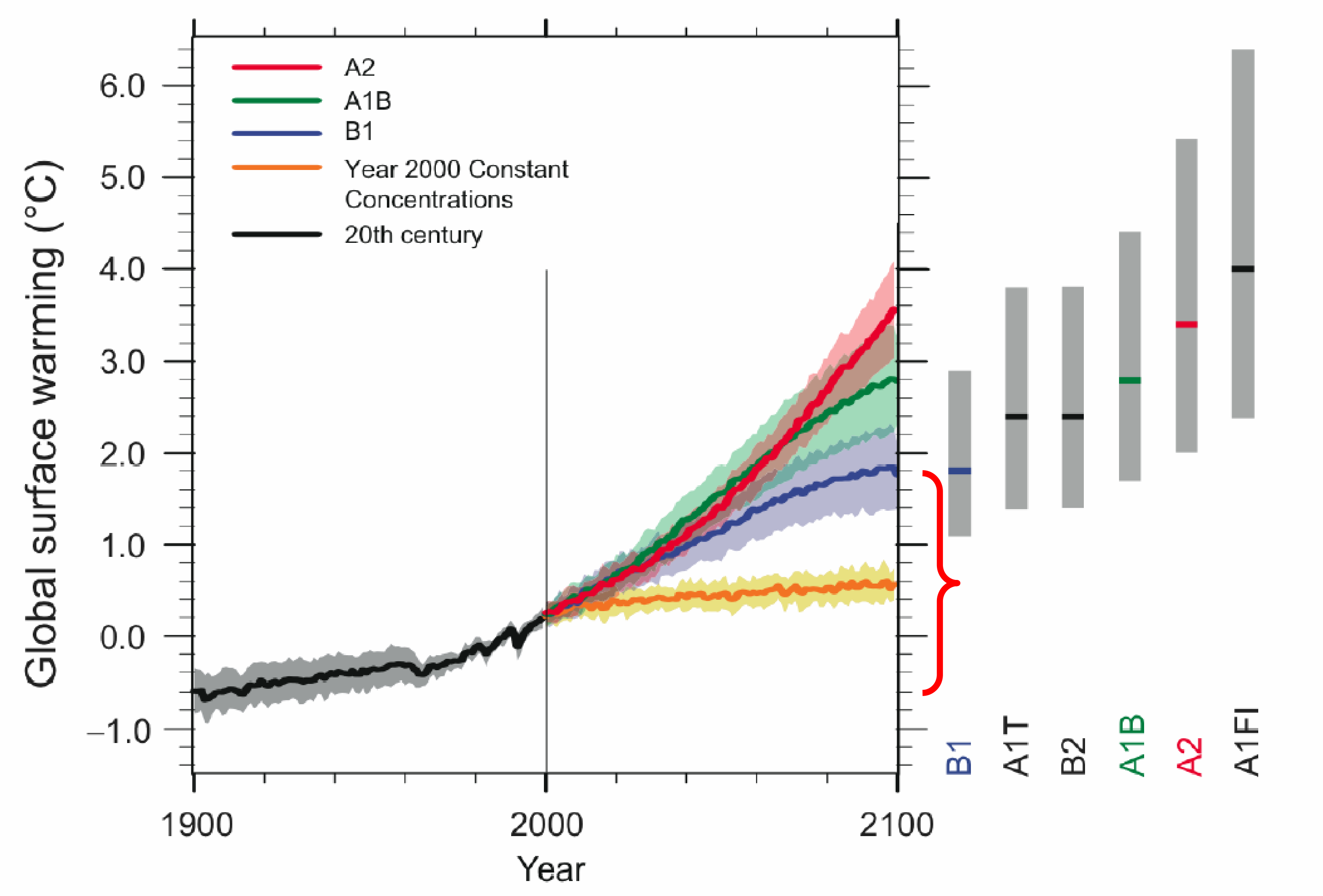
Italy &
Greece 2007

Sylvensteinspeicher
(upper Isar) 2007

Rhine 2003
Düsseldorf

Droughts in Europa

Global Climate Change: What We Expect

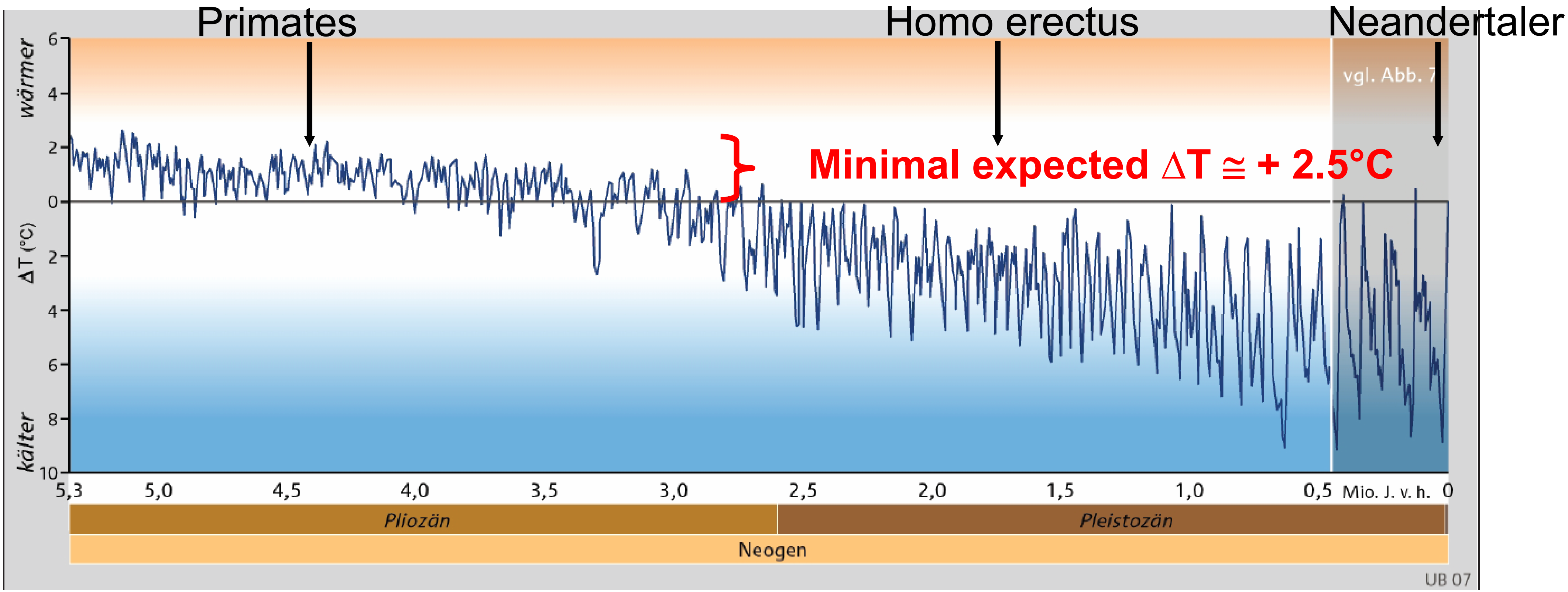


Even optimistic scenarios: 2.5°C ↑

IPCC, 4AR

Global Climate Change: What We Expect

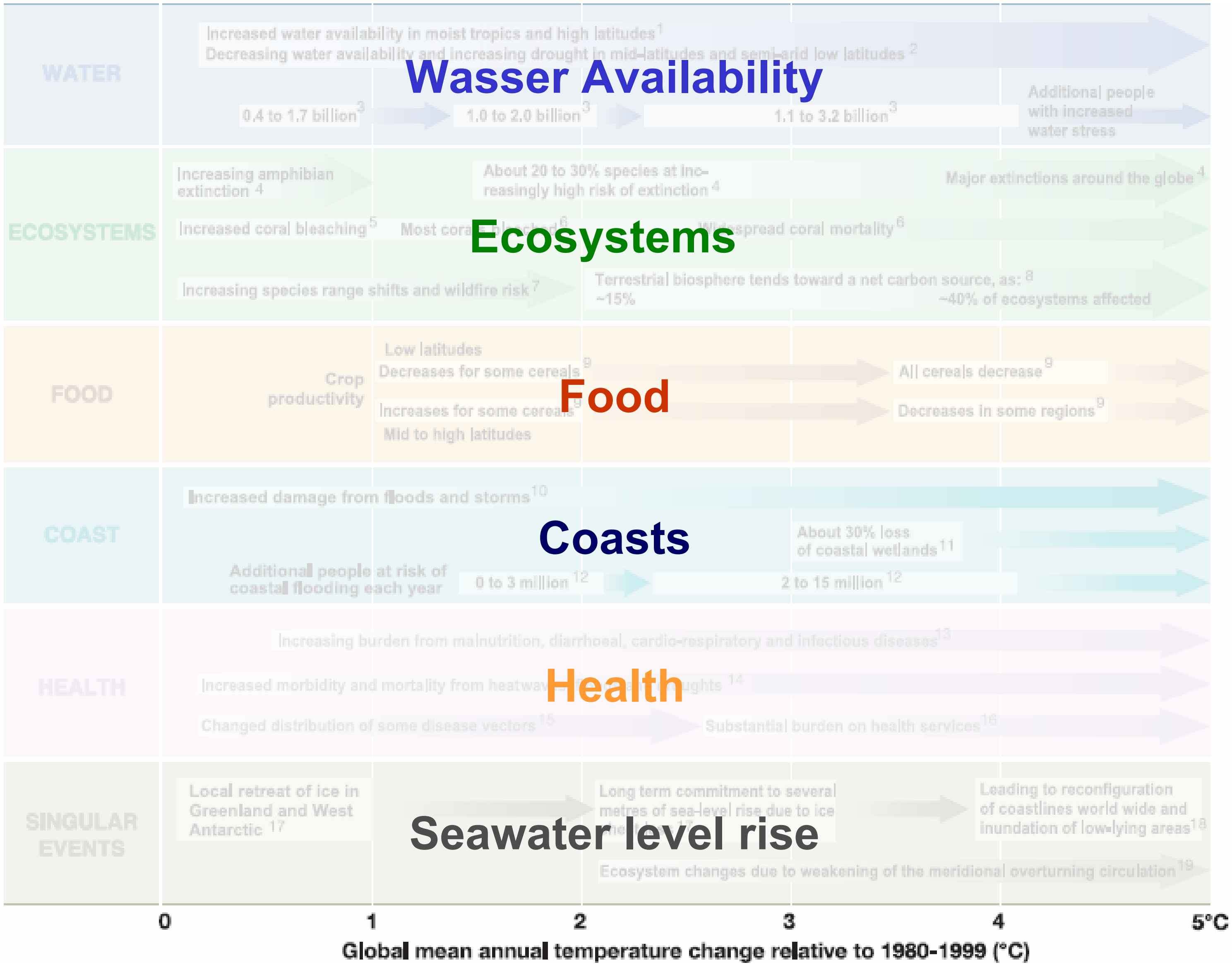
Global past temperature changes vs. today's mean



Nach Lisiecki nund Raymo, 2005

Expected ΔT ⇒ no comparable climate periods in last 5 Mill. years!

Global Climate Change: Consequences



Wasser Availability

Ecosystems

Food

Coasts

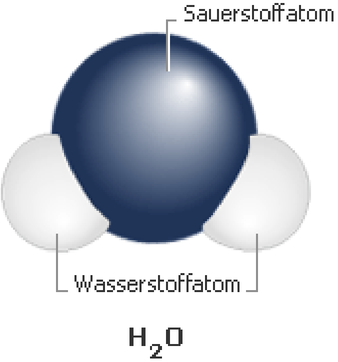
Health

Seawater level rise

IPCC, 4AR

Climate and Water: More than H_2O

Floods



Water shortage

Looking into the Future: Climate Scenarios

Population Growth Economic Development
Technological Progress

⇩

Emission Scenarios
Greenhouse Gas Concentrations

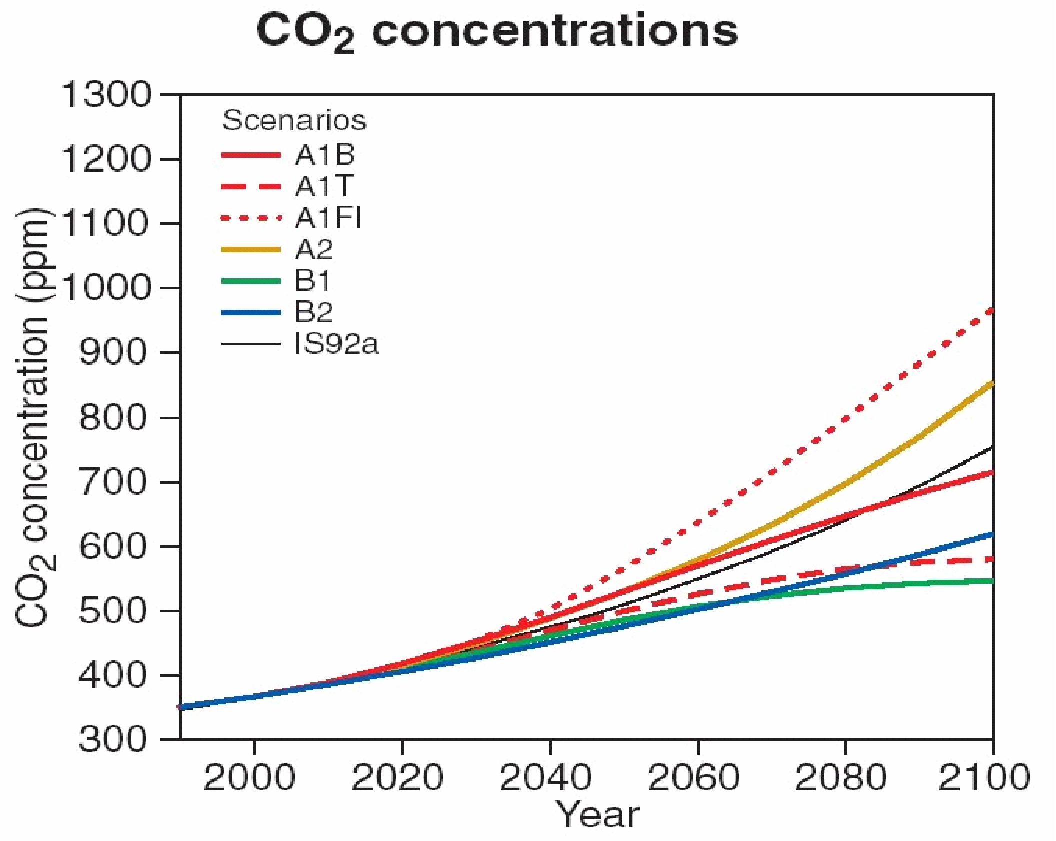
⇩

Global Climate Models

⇩

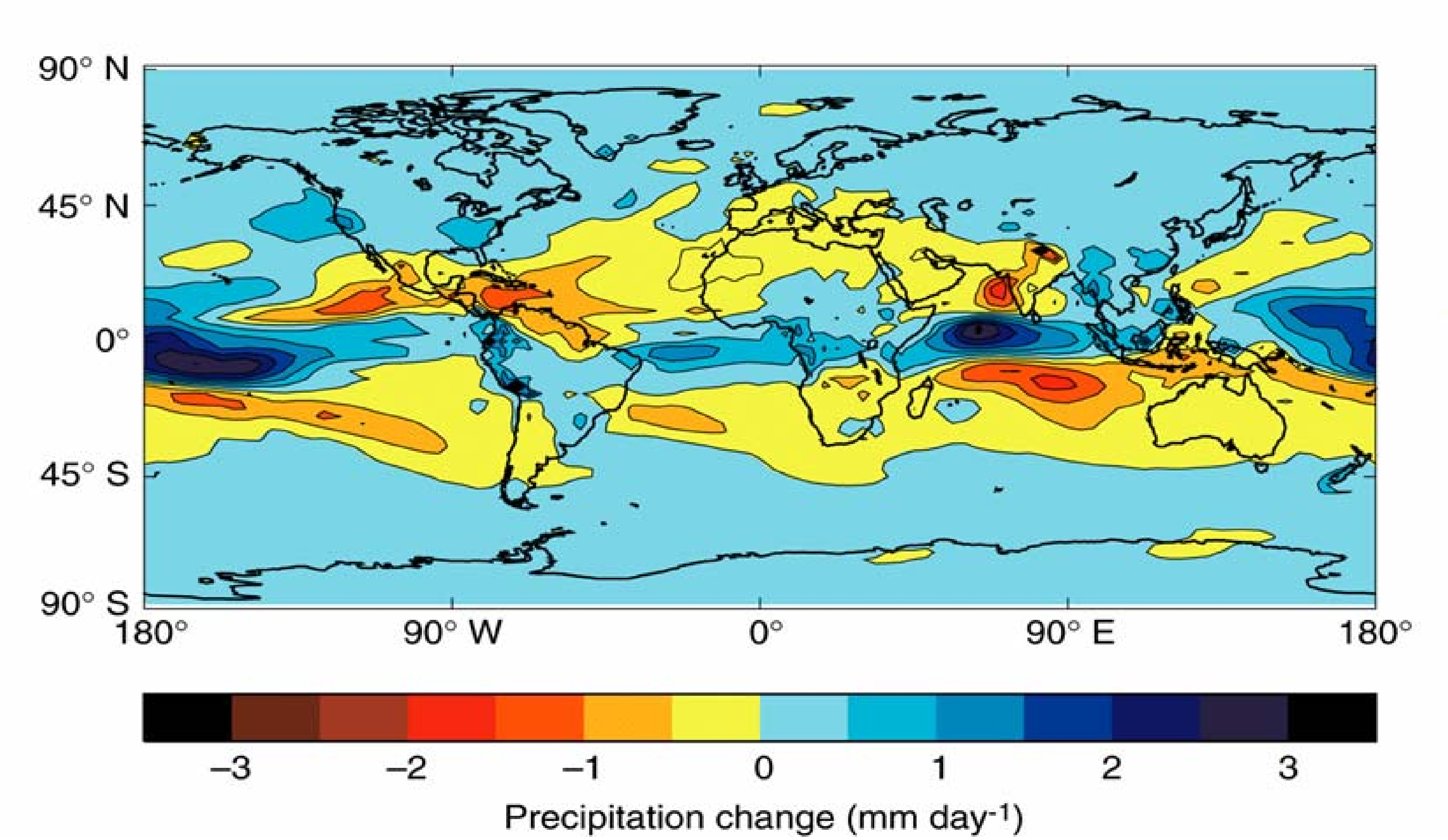
Global Climate Scenarios

Looking into the Future: Climate Scenarios



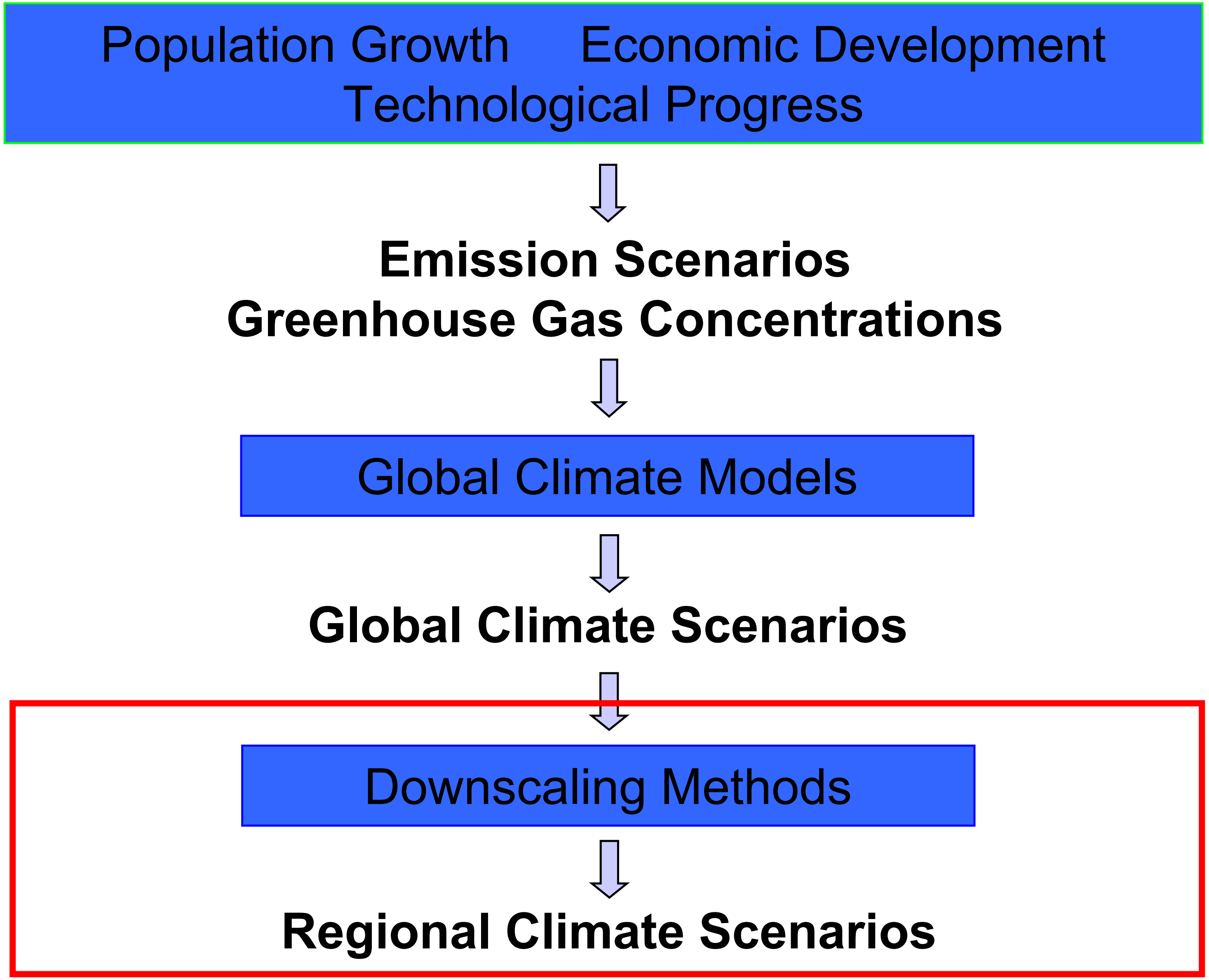
Looking into the Future: Climate Scenarios

Global Climate Scenarios:
Projected Changes in Annual Precipitation for the 2050s



Hadley Centre for Climate Prediction and Research

⇒ Resolution too coarse for regional impact analysis !



Population Growth Economic Development
Technological Progress

Emission Scenarios
Greenhouse Gas Concentrations

Global Climate Models

Global Climate Scenarios

Downscaling Methods

Regional Climate Scenarios

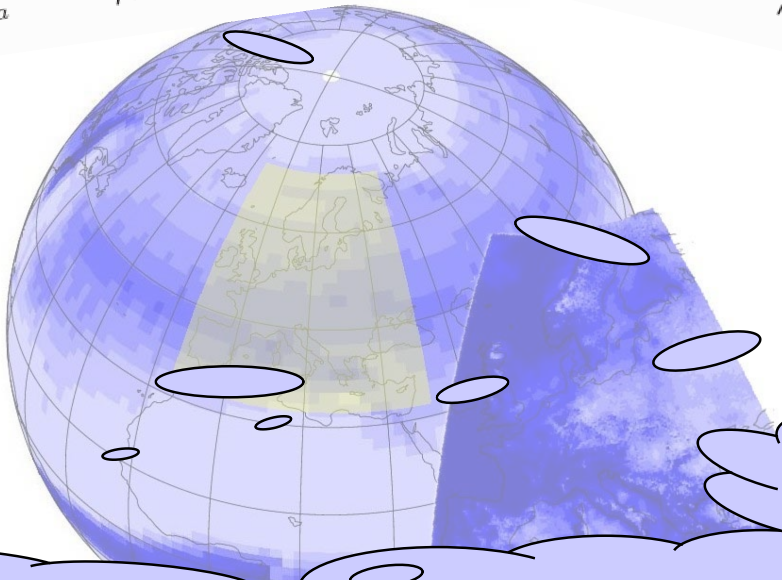
Regional Climate Modeling

Momentum conservation

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\cdot\nabla)\,\vec{v} = -f\vec{k}\times\vec{v} - \nabla\Phi - \frac{1}{\rho_a}\nabla p_a + \frac{\eta_a}{\rho_a}\nabla^2\vec{v} + \frac{1}{\rho_a}\left(\nabla\cdot\rho_a\mathbf{K_m}\nabla\right)\vec{v}$$

Energy conservation

$$\frac{\partial\theta_v}{\partial t} + (\vec{v}\cdot\nabla)\,\theta_v = \frac{1}{\rho_a}\left(\nabla\cdot\rho_a\mathbf{K_h}\nabla\right)\theta_v + \frac{\theta_v}{c_{p,d}T_v}\sum_{n=1}^{N}\frac{dQ_n}{dt}$$



Gas law

$$p = \frac{nR^*T}{V}$$

Air mass conservation

$$\frac{\partial\rho_a}{\partial t} + \nabla\cdot(\vec{v}\rho_a) = 0$$

Conservation water mass

$$\begin{aligned}
\frac{\partial q_v}{\partial t} + (\vec{v}\cdot\nabla)\,q_v &= \frac{1}{\rho_a}\left(\nabla\rho_a\mathbf{K_h}\nabla\right)q_v + R_{evap} - R_{cond} - R_{iini} - R_{idep/sub}\\
\frac{\partial q_c}{\partial t} + (\vec{v}\cdot\nabla)\,q_c &= \frac{1}{\rho_a}\left(\nabla\rho_a\mathbf{K_h}\nabla\right)q_c + R_{cond} + R_{iini} + R_{idep/sub} - R_{aconv} - R_{accr}\\
\frac{\partial q_r}{\partial t} + (\vec{v}\cdot\nabla)\,q_r &= \frac{1}{\rho_a}\left(\nabla\rho_a\mathbf{K_h}\nabla\right)q_r - R_{evap} + R_{aconv} + R_{accr} - \frac{\partial V_f\rho_a g q_r}{}
\end{aligned}$$

Energy conservation at land surface

$$\begin{aligned}
L_vE + H + G &= SW_{net} + LW_{net}\\
&= (1-\alpha)SW\downarrow + LW\downarrow - \epsilon\,\sigma_B\,T^4_{surf}
\end{aligned}$$

Soil temperature diffusion

$$C(\Theta)\frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z}\left[K_t(\Theta)\frac{\partial T_s}{\partial z}\right]$$

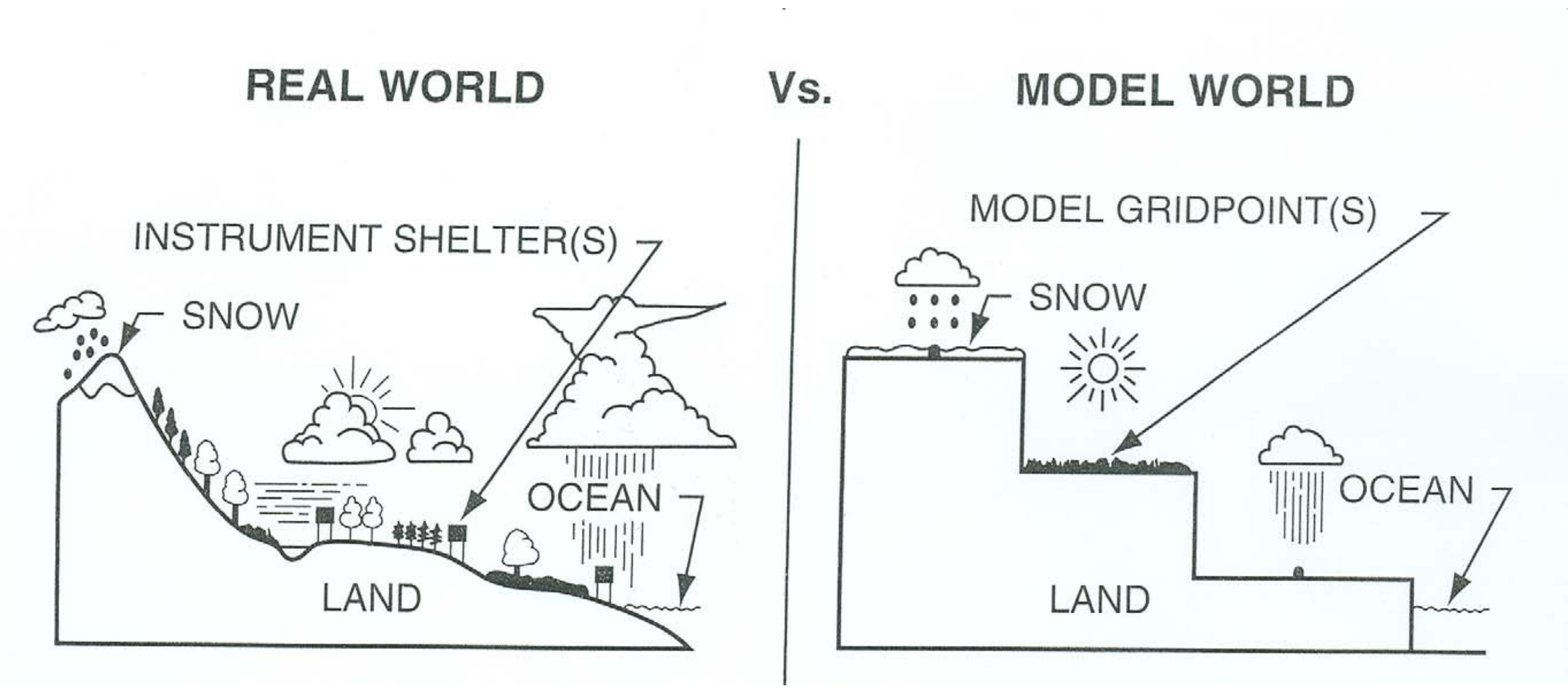
Precipitation physics

$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w-1)}{A_r+B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r\rho}{\eta_a}\right)^{1/2} S_c^{1/3}\frac{\Gamma(5/2+b_r/2)}{\Lambda_r^{5/2+b_r/2}}\right]$$

Soil water infiltration

$$\frac{\partial\Theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\Theta)\frac{\partial\Theta}{\partial z}\right] + \frac{\partial k(\Theta)}{\partial z}$$

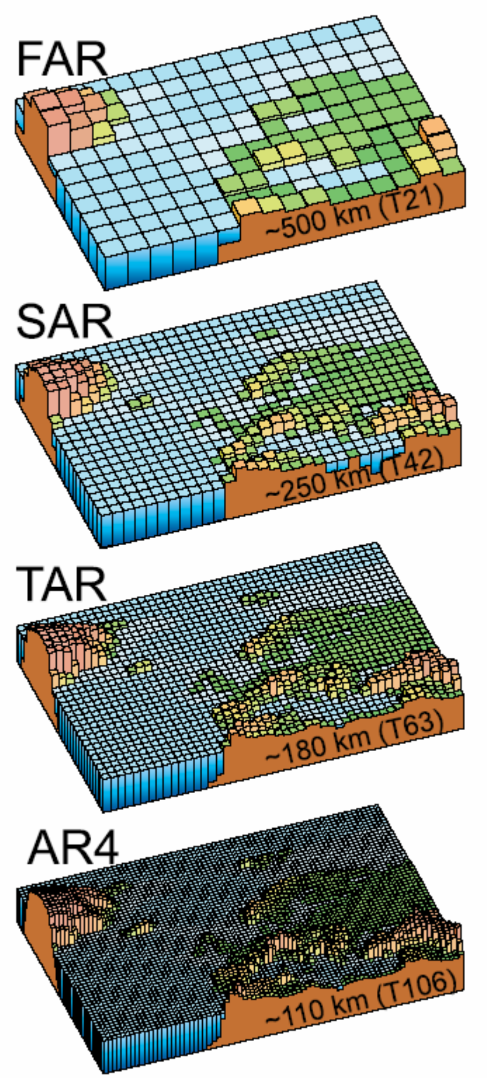
Regional Climate Modeling

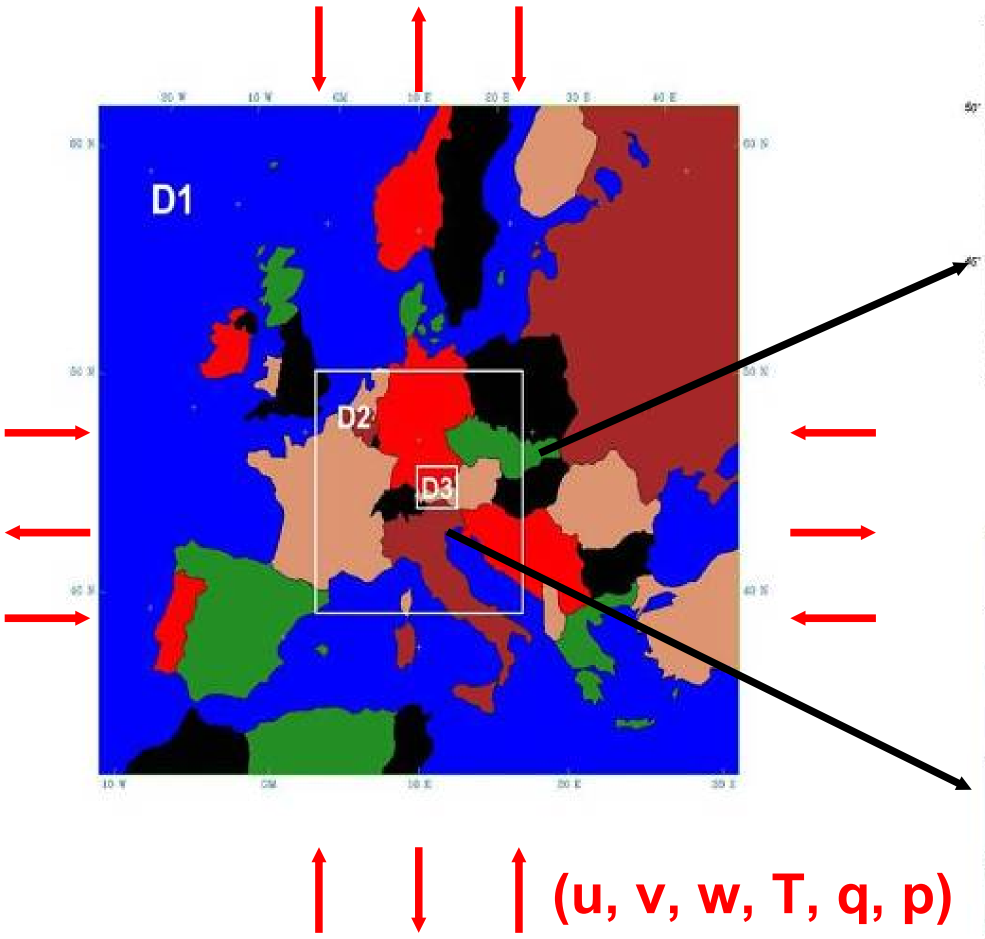


Regional Climate Modeling

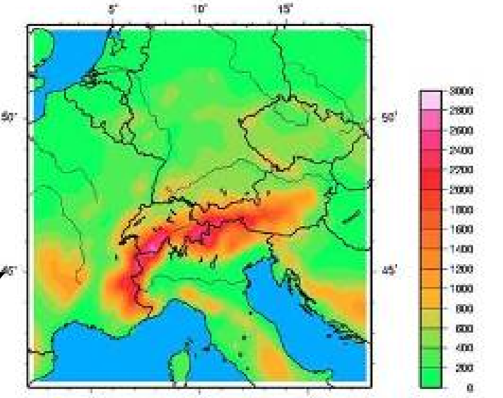
RCM: driven by GCM (Initial and boundary value problem)

High spatial resolution ⇒ detailed orography

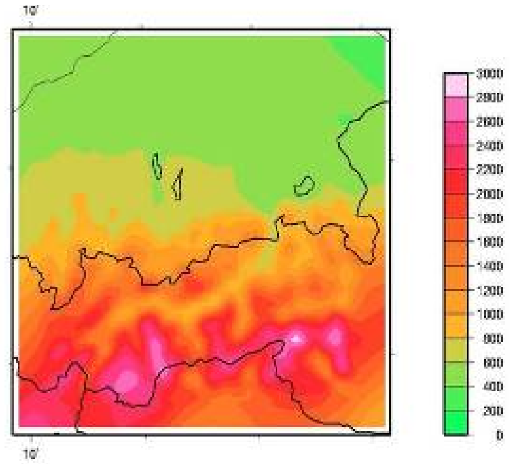




(u, v, w, T, q, p)



Orography in 20x20 km² resolution



Orography in 4x4 km² resolution

Regional Climate Modeling & Hydrological Impact

1) Flood risks in Alpine Space

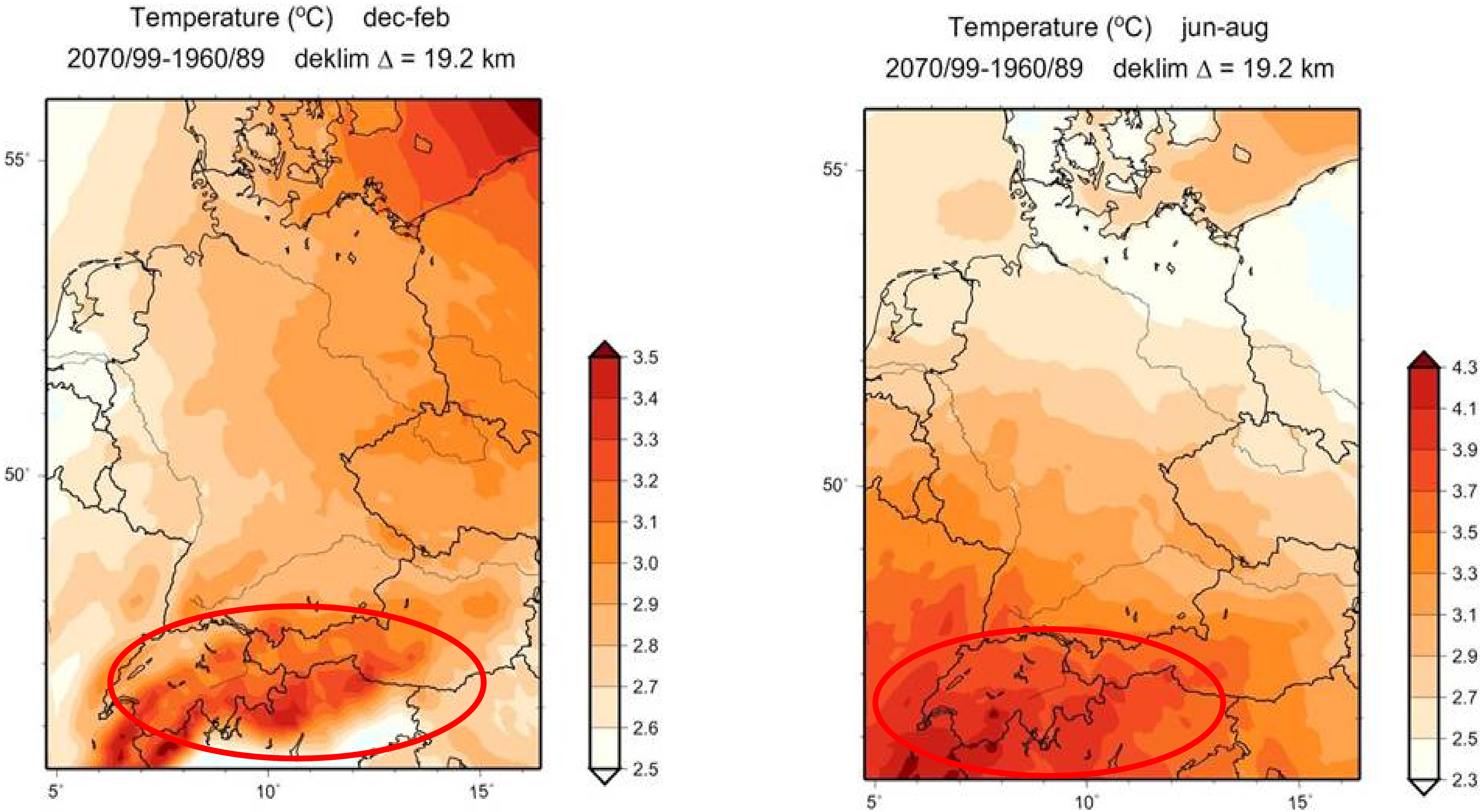
2) Water Availability in the Near East

Example 1

Regional Climate Change

Germany/Southern Germany & Alps

Regional Climate Modeling



Temperature (°C) dec-feb
2070/99-1960/89 deklim Δ = 19.2 km

Temperature (°C) jun-aug
2070/99-1960/89 deklim Δ = 19.2 km

Winter

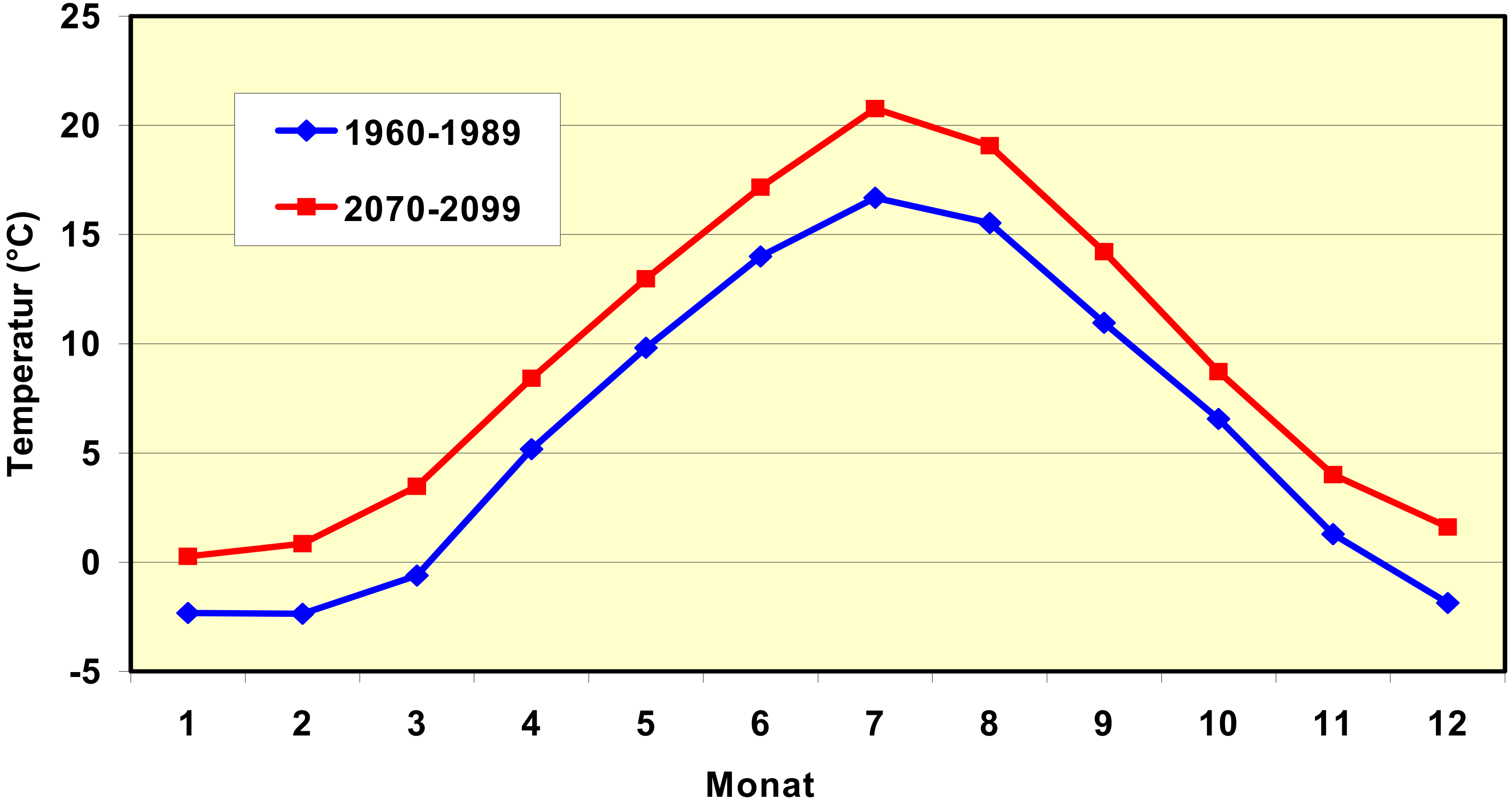
Sommer

Alpine area: 3-4°C „hot spot“ in Europe

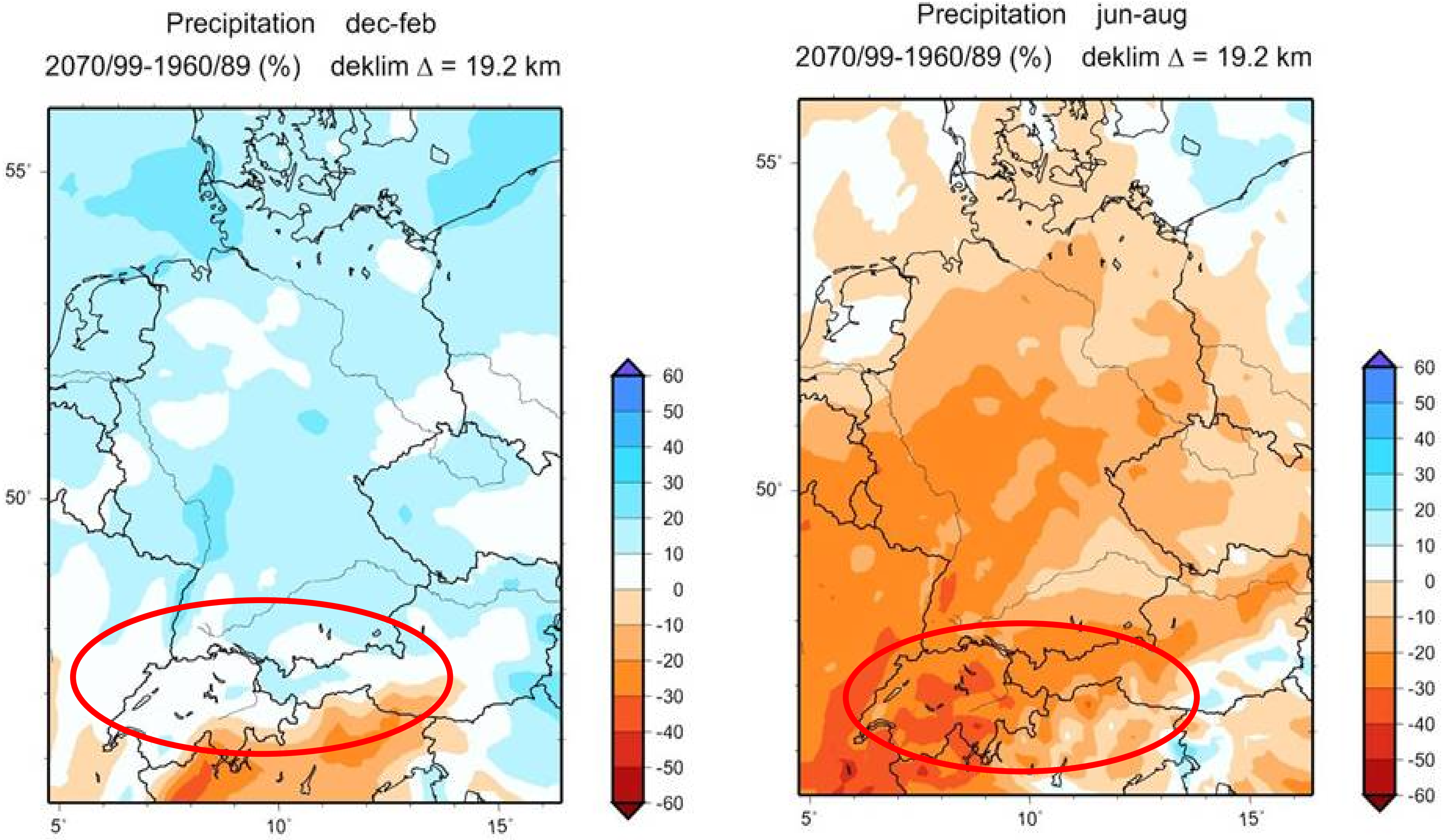
Regional Climate Modeling

Regional Climate Change Southern Germany

Temperature Change [°C] , 2070-99 vs. 1960-89, Δ=19km



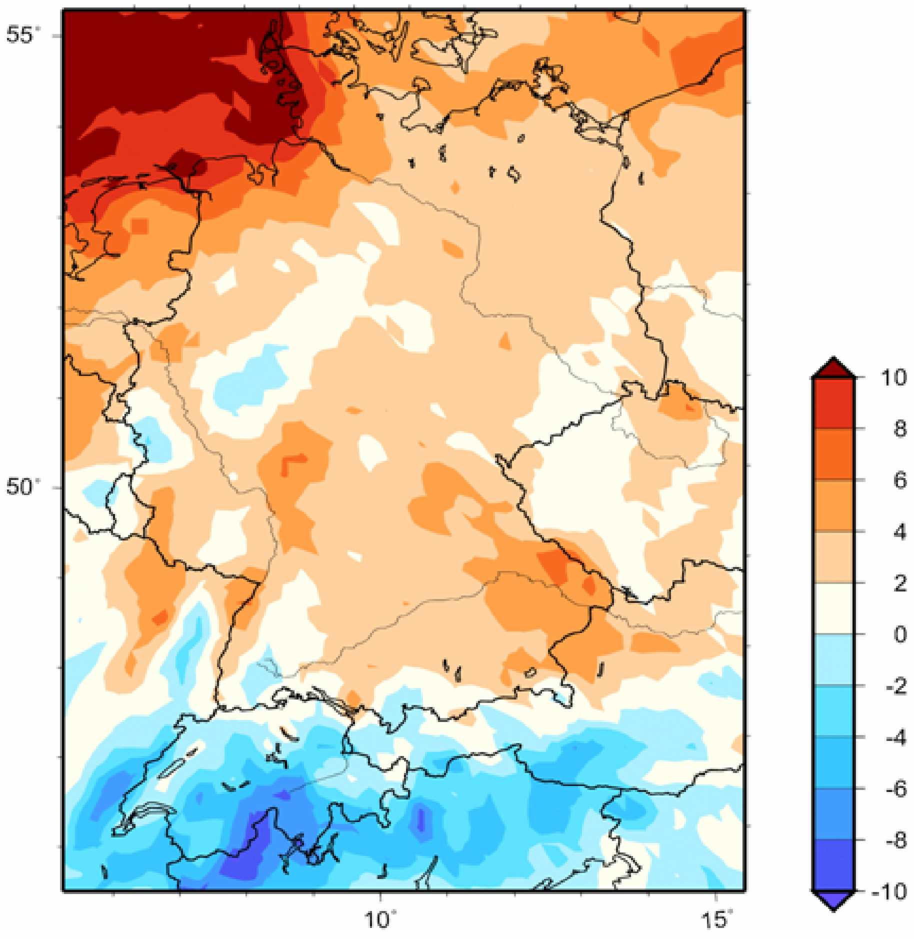
Regional Climate Modeling



Up to 30% more precipitation in winter (Europe ≈ +11%)
Up to 40% less precipitation in summer (Europe ≈ -1%)

Regional Climate Modeling

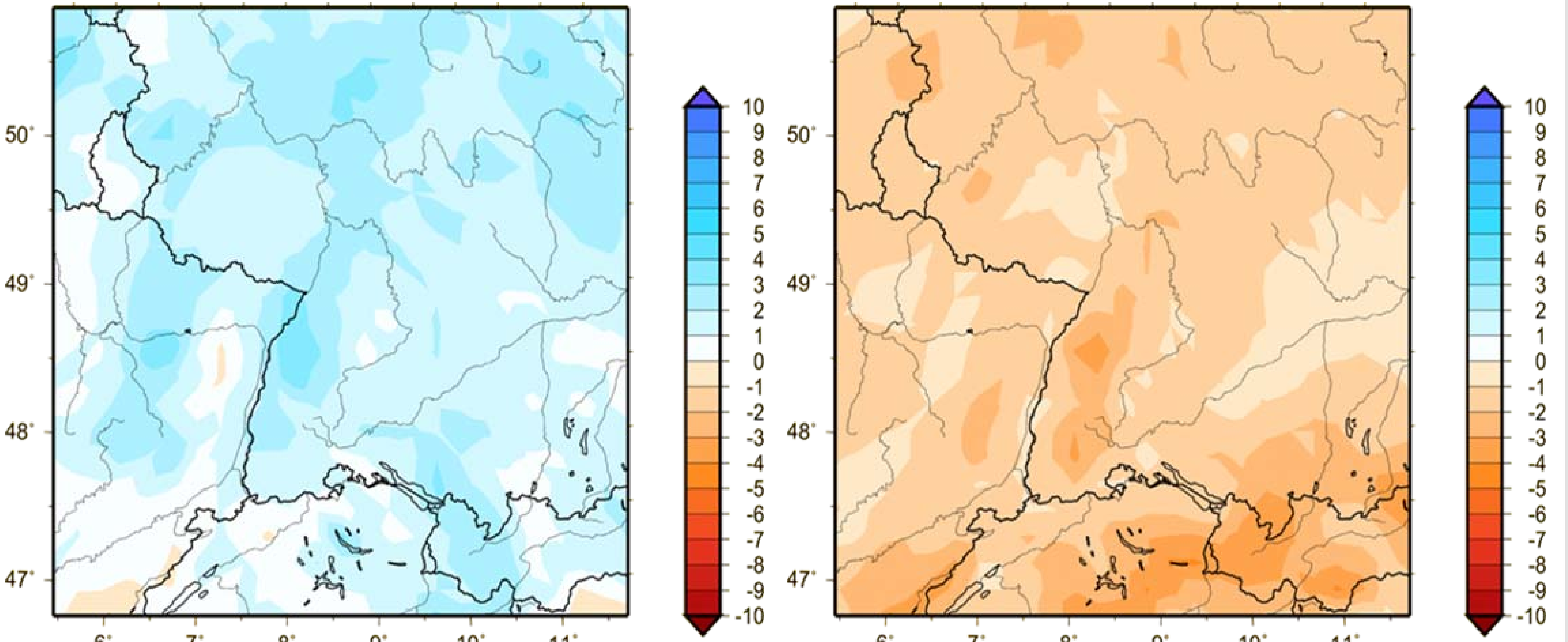
Change in frequency of heavy precipitation (2070-99 vs. 1960-89)



Change in number of days/year P > 10 mm

Regional Climate Modeling

Change in frequency of heavy precipitation P > 10mm



Winter DJF

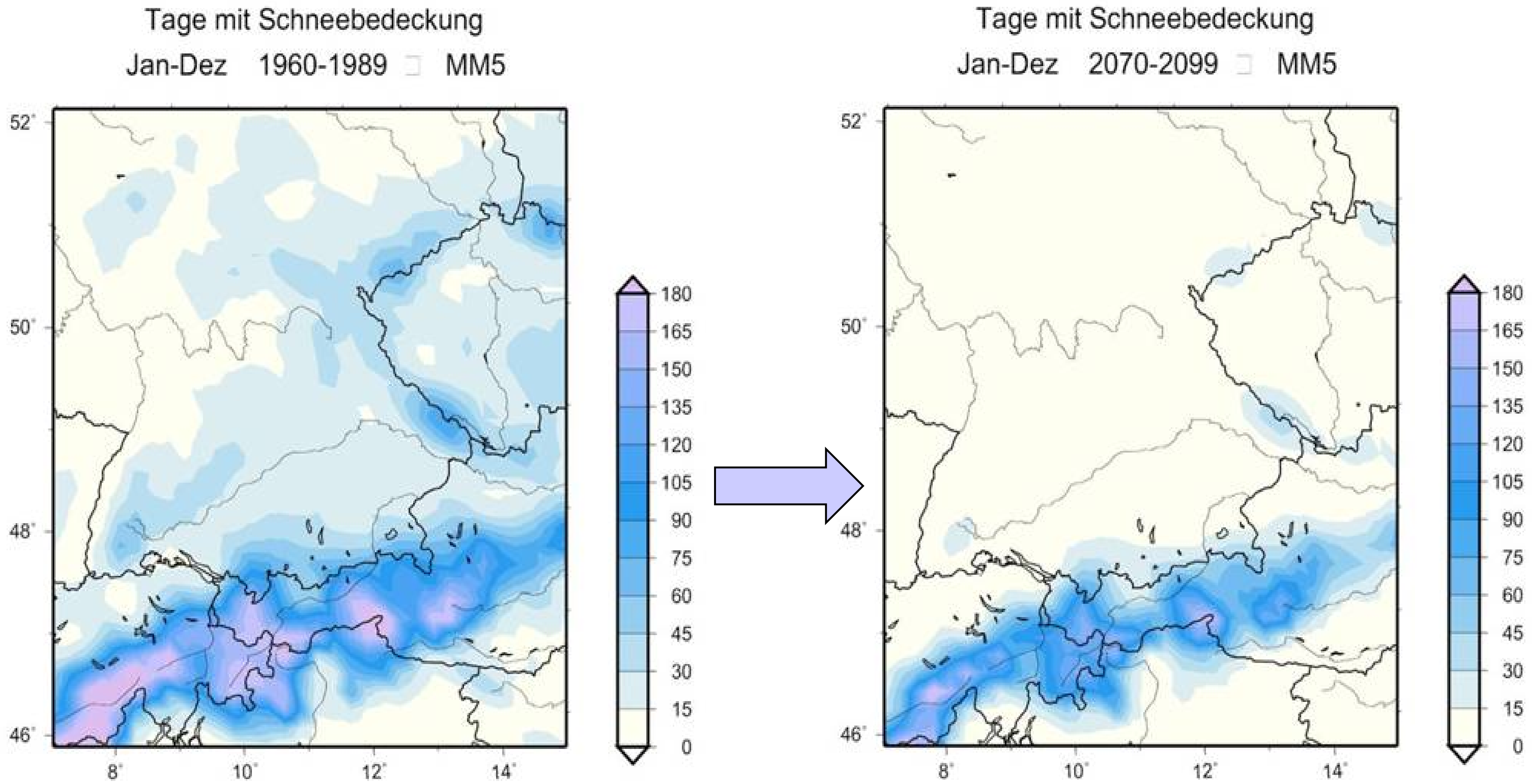
Summer JJA

Increase of days with heavy precipitation in winter

Decrease of days with heavy precipitation in summer

Regional Climate Modeling

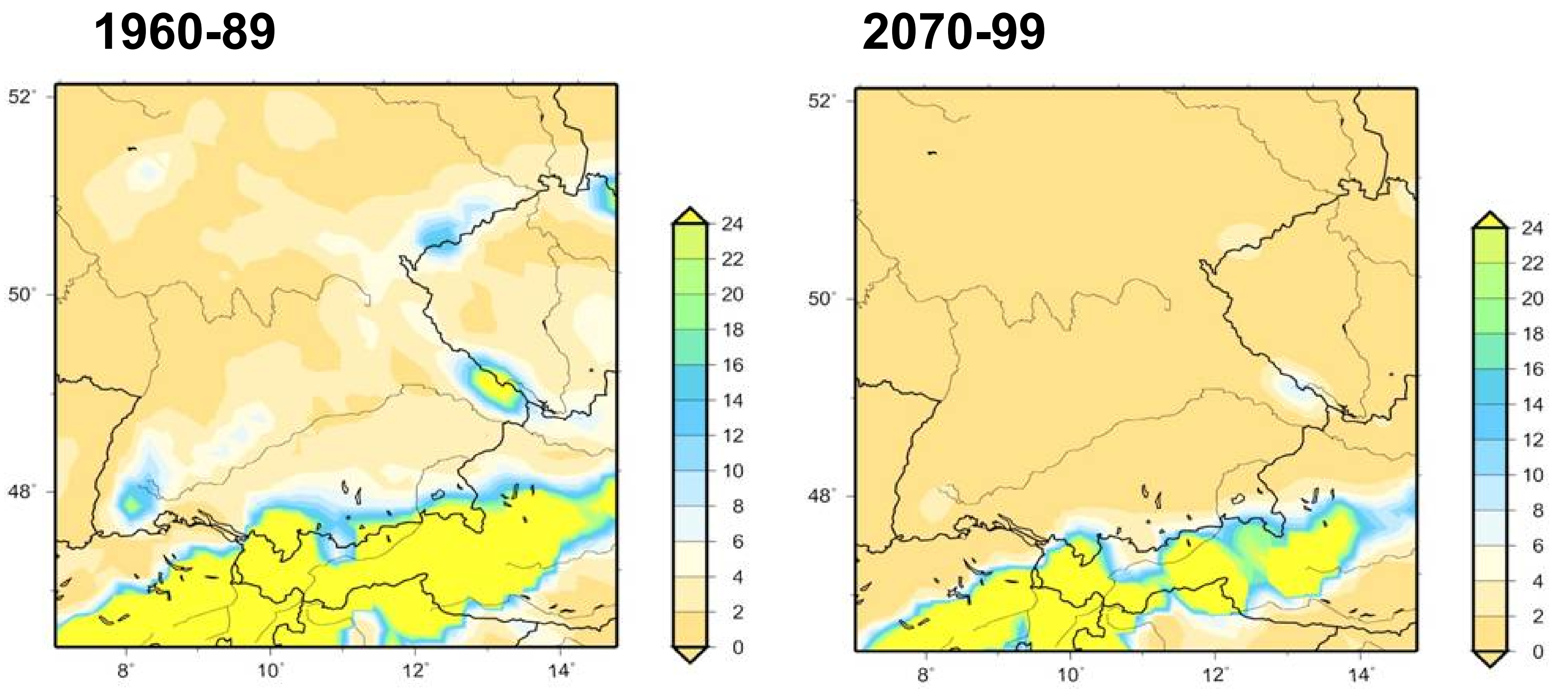
Days with Snow Cover



Decrease of number of days with snow cover

Regional Climate Modeling

Snow mass in [mm] water equivalent   Dec-Feb

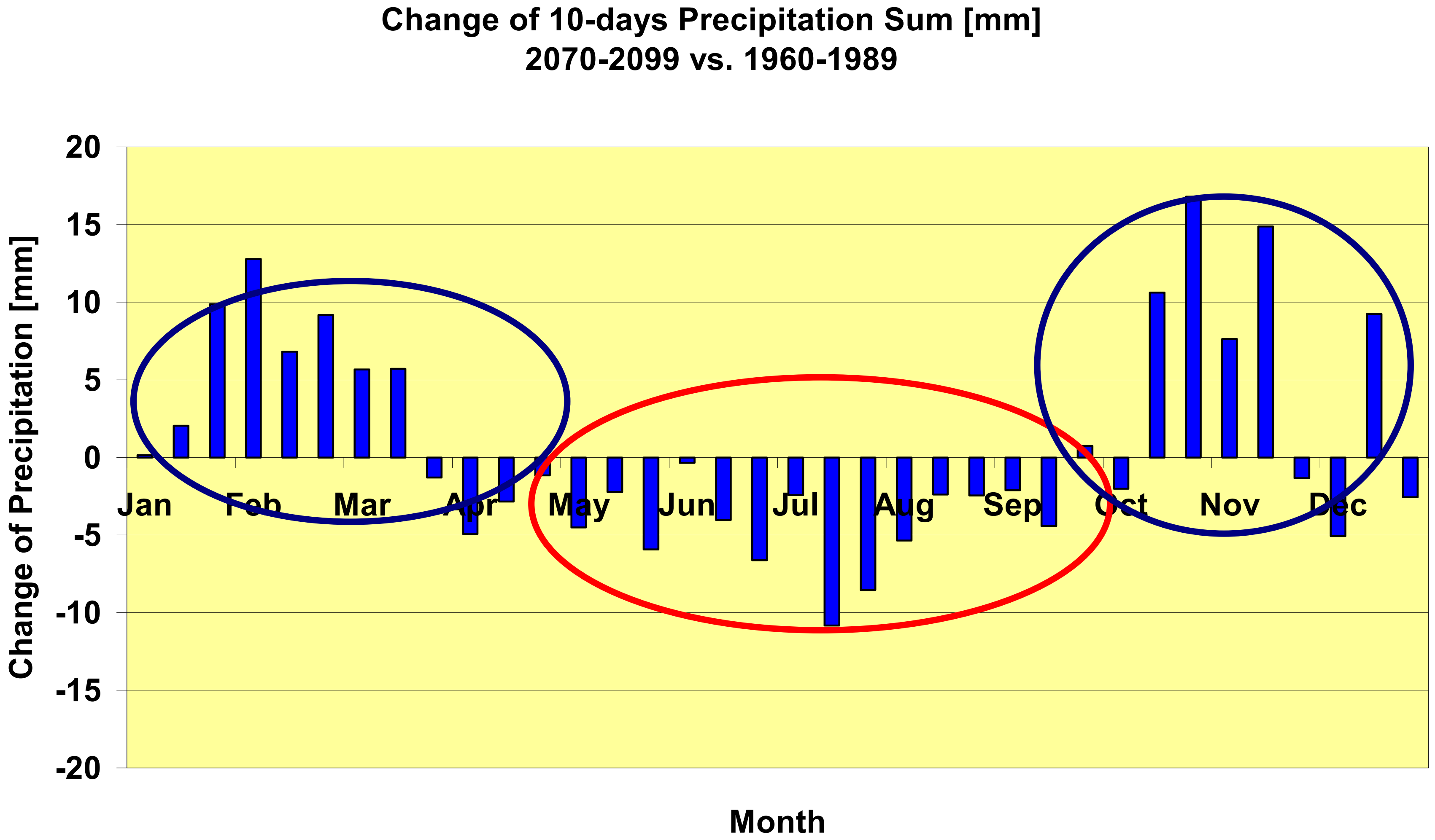


1960-89

2070-99

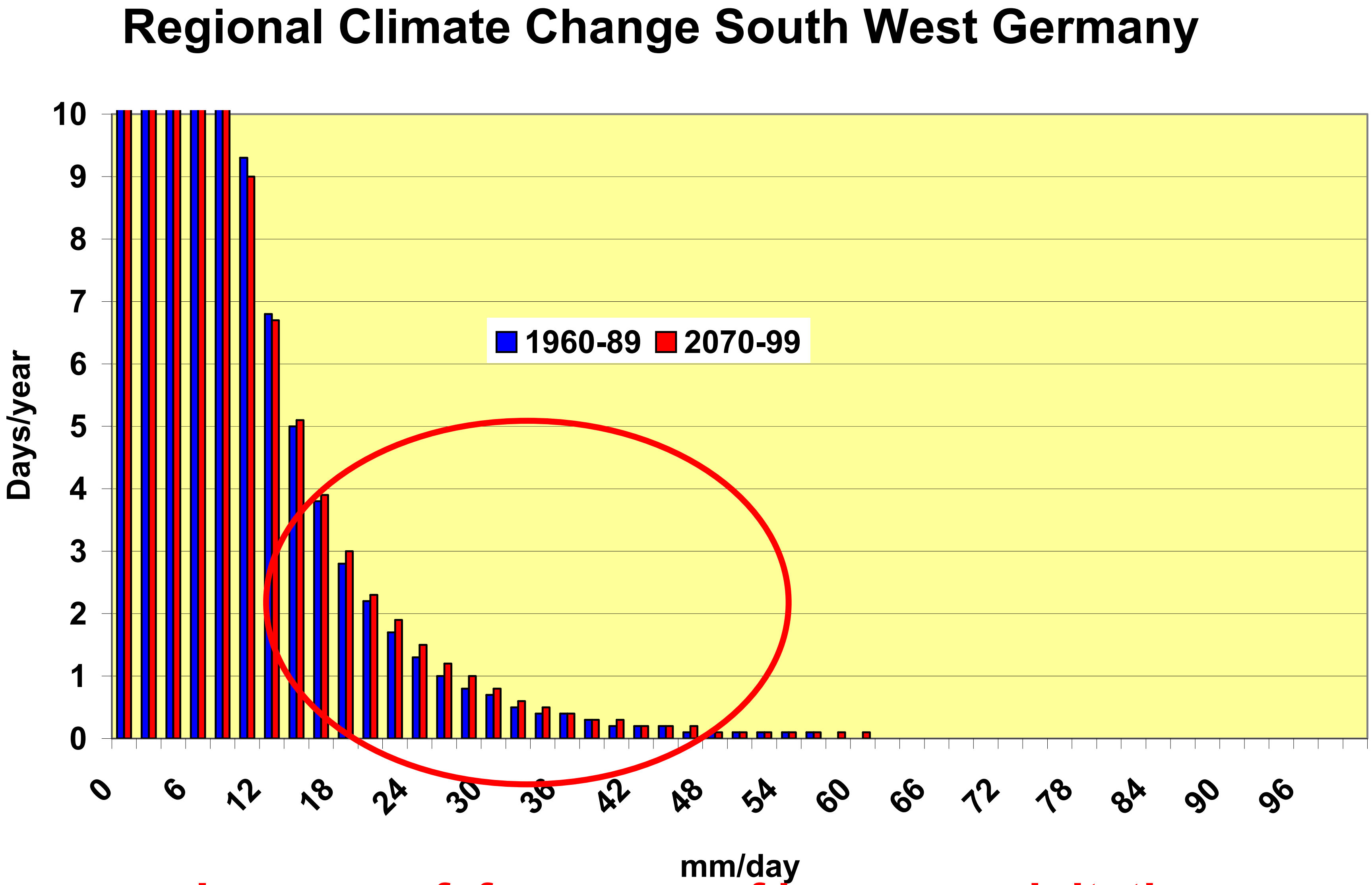
Regional Climate Modeling

Regional Climate Change South West Germany



Increased winter-, decreased summer precipitation

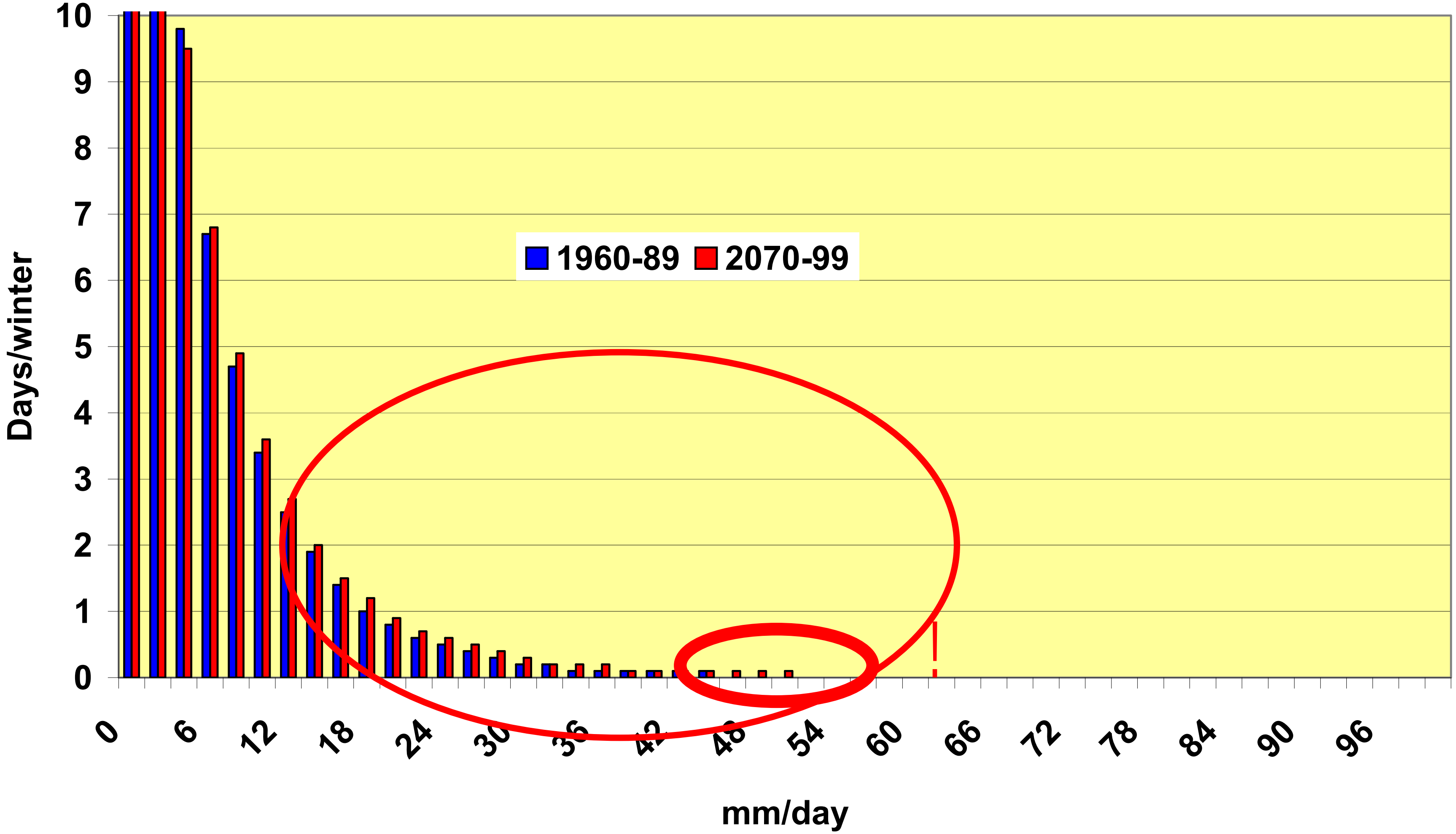
Regional Climate Modeling



Increase of frequency of heavy precipitation

Regional Climate Modeling

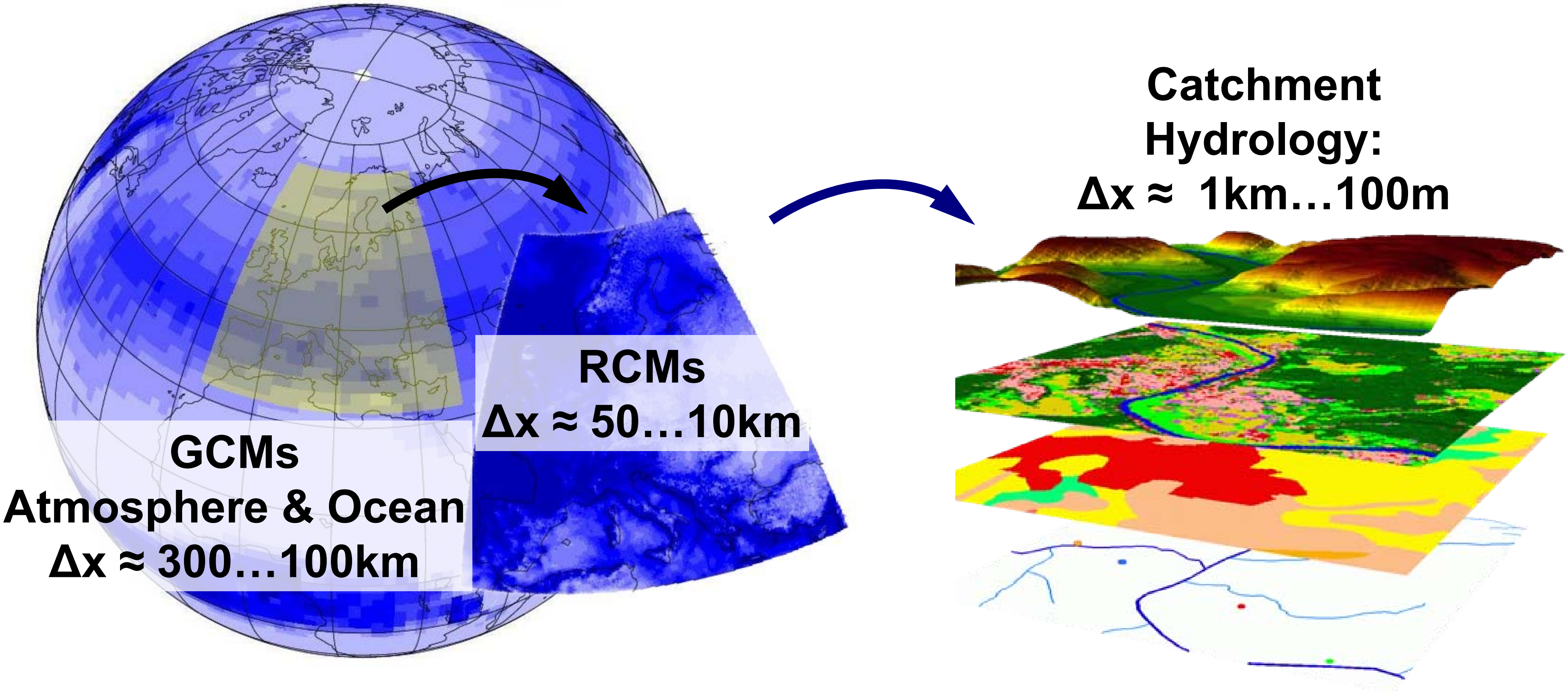
Regional Climate Change South West Germany



Winter (DJF): Increase of frequency of heavy precipitation

Hydrological Impact Analysis

Scale gaps



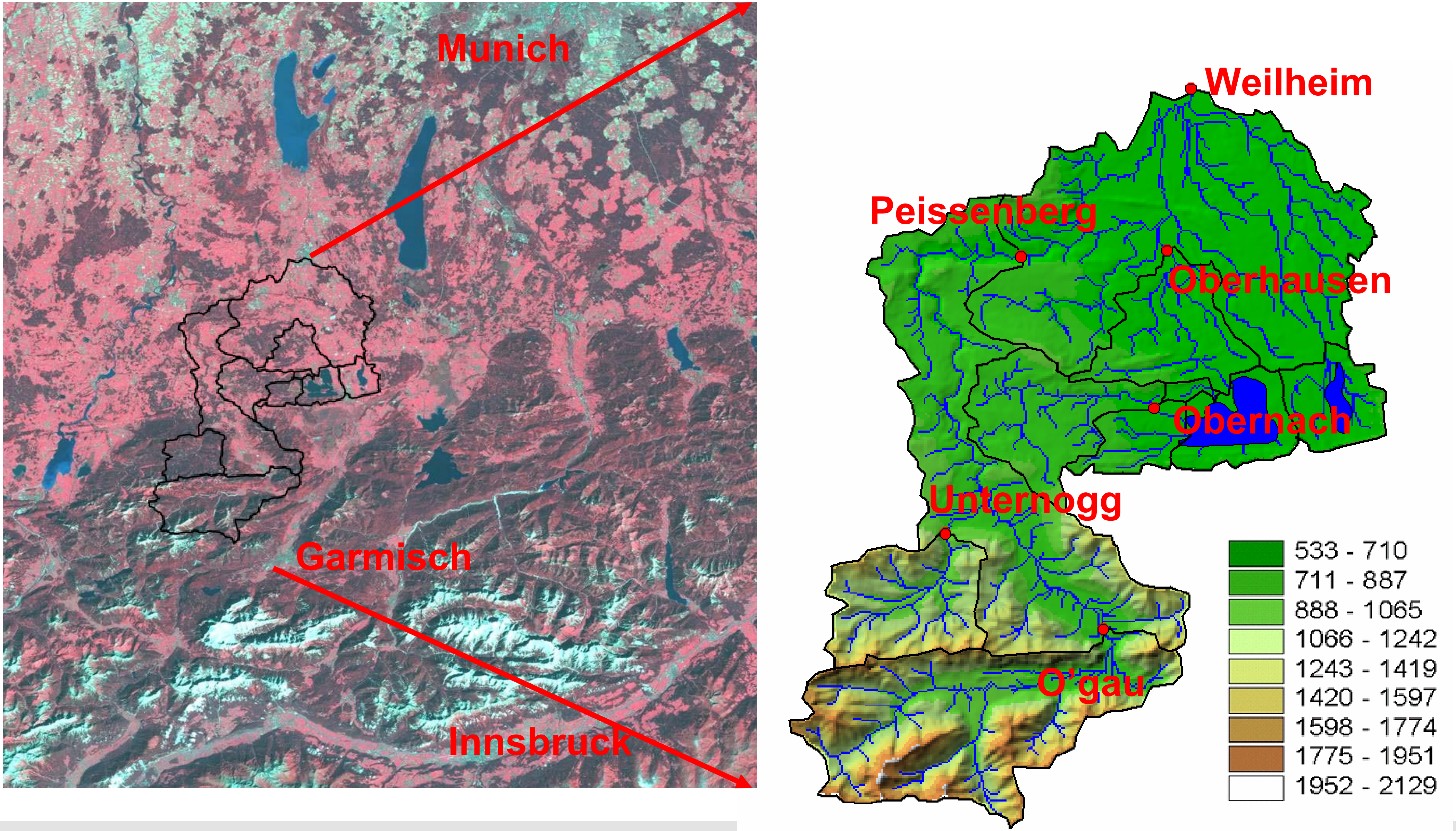
GCMs
Atmosphere & Ocean
Δx ≈ 300…100km

RCMs
Δx ≈ 50…10km

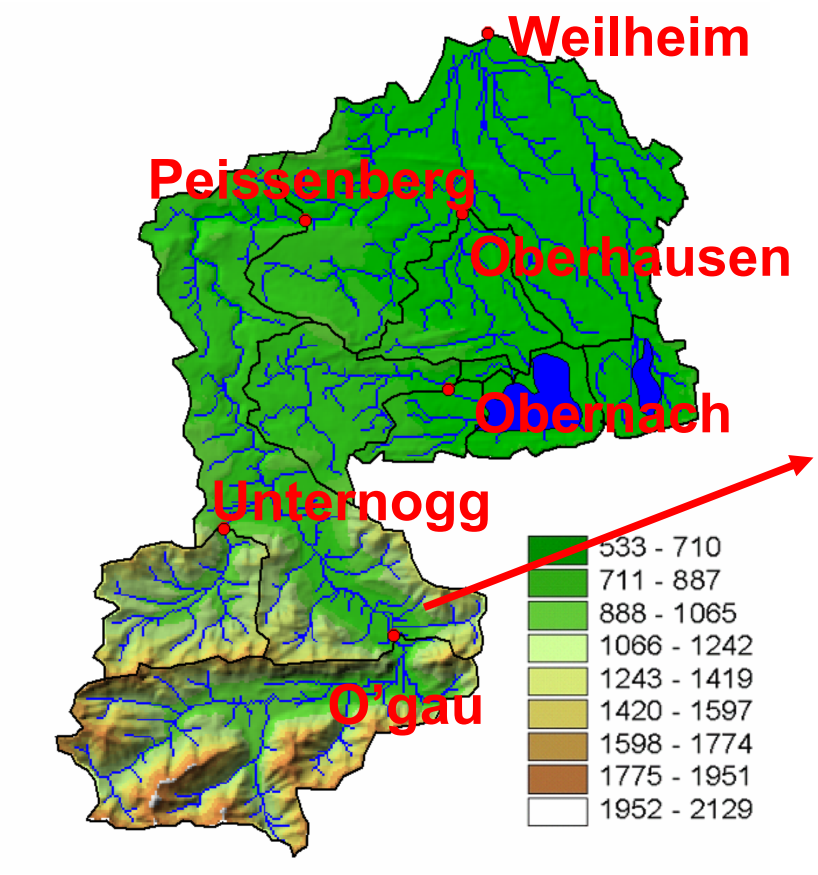
Catchment Hydrology:
Δx ≈ 1km…100m

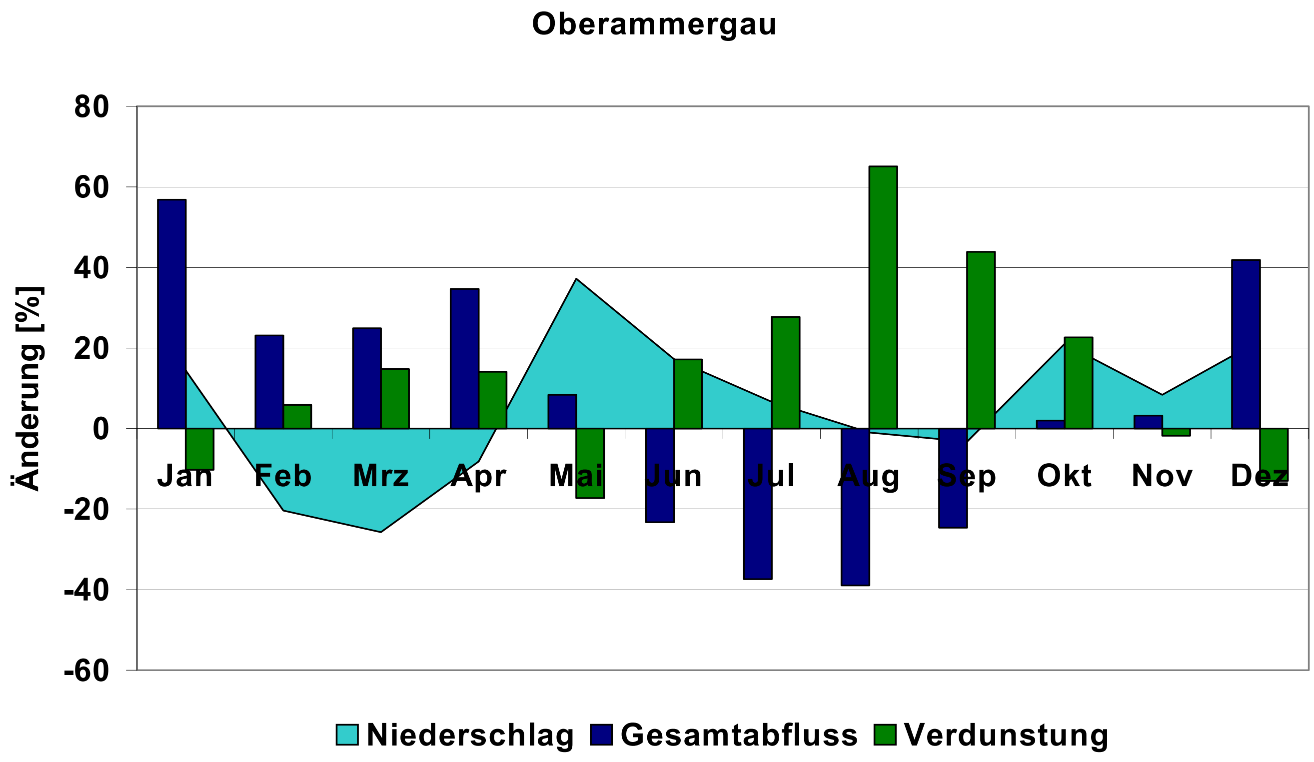
Dynamic downscaling by RCMs

Case Study: Catchment of the River Ammer



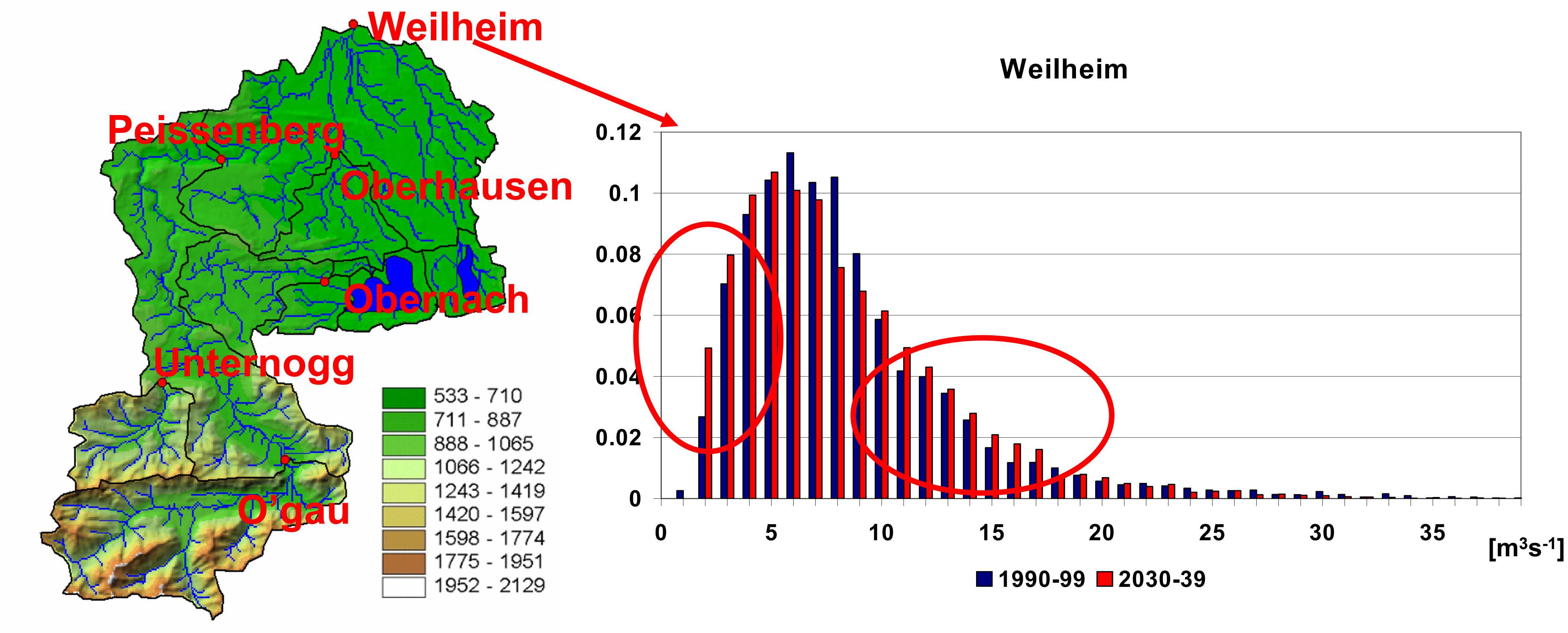
Impact Climate Change on Hydrology





Increase winter-, decrease summer runoff

Impact Climate Change on Hydrology



Change of frequencies: increase of both flooding and low water!

Example 2

Regional Climate Change

Eastern Mediterranean/Near East

& Upper Jordan River Catchment

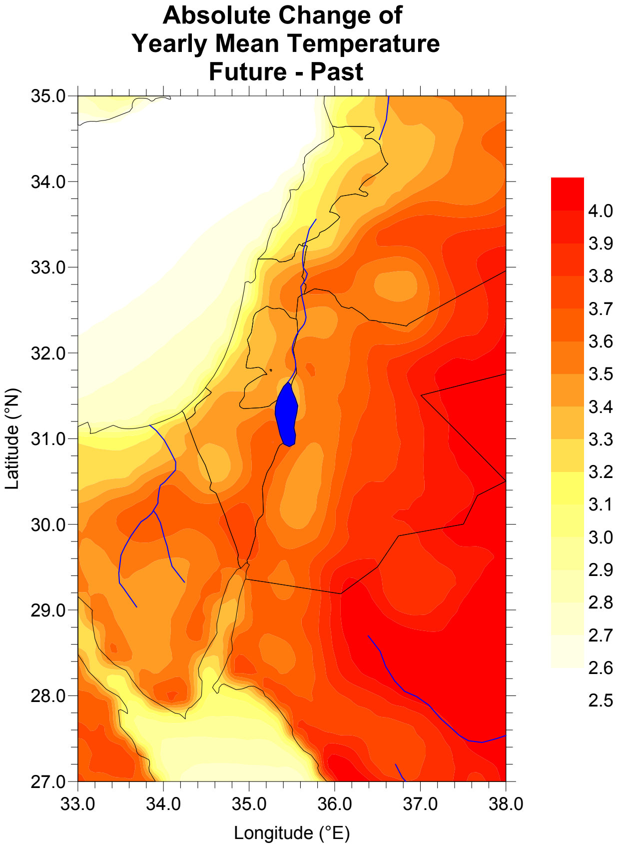
Regional Climate Change EM/ME

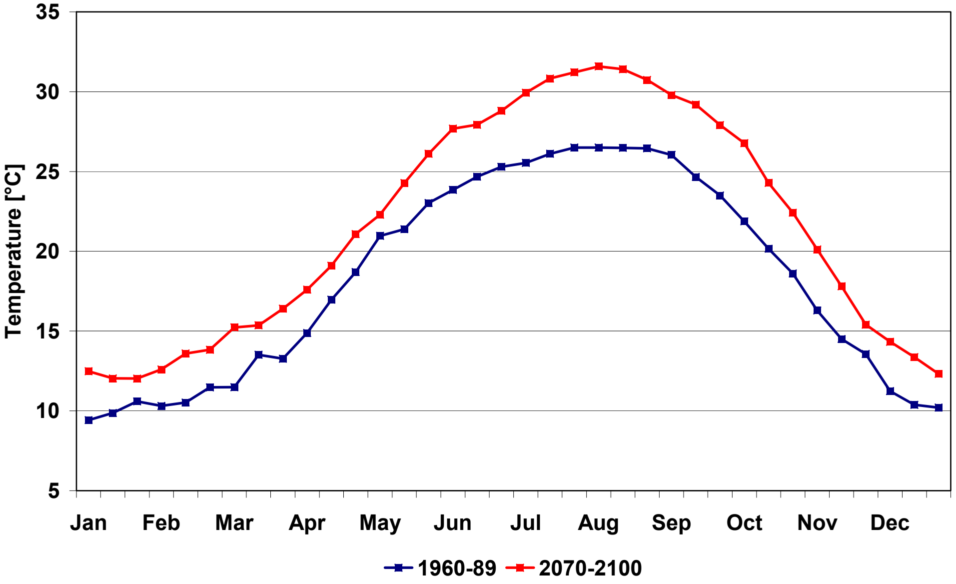
Motivation

- Water availability per capita in the Middle East one of the lowest worldwide (150 m³/a)
- Distribution of resource freshwater has high conflict potential
- Future availability may be further restricted by population pressure and **climate change**
- Specific hydrological focus: Upper Jordan catchment (⇒ provides 1/3rd of drinking water resources in Israel)

Regional Climate Change & Water Availability EM/ME

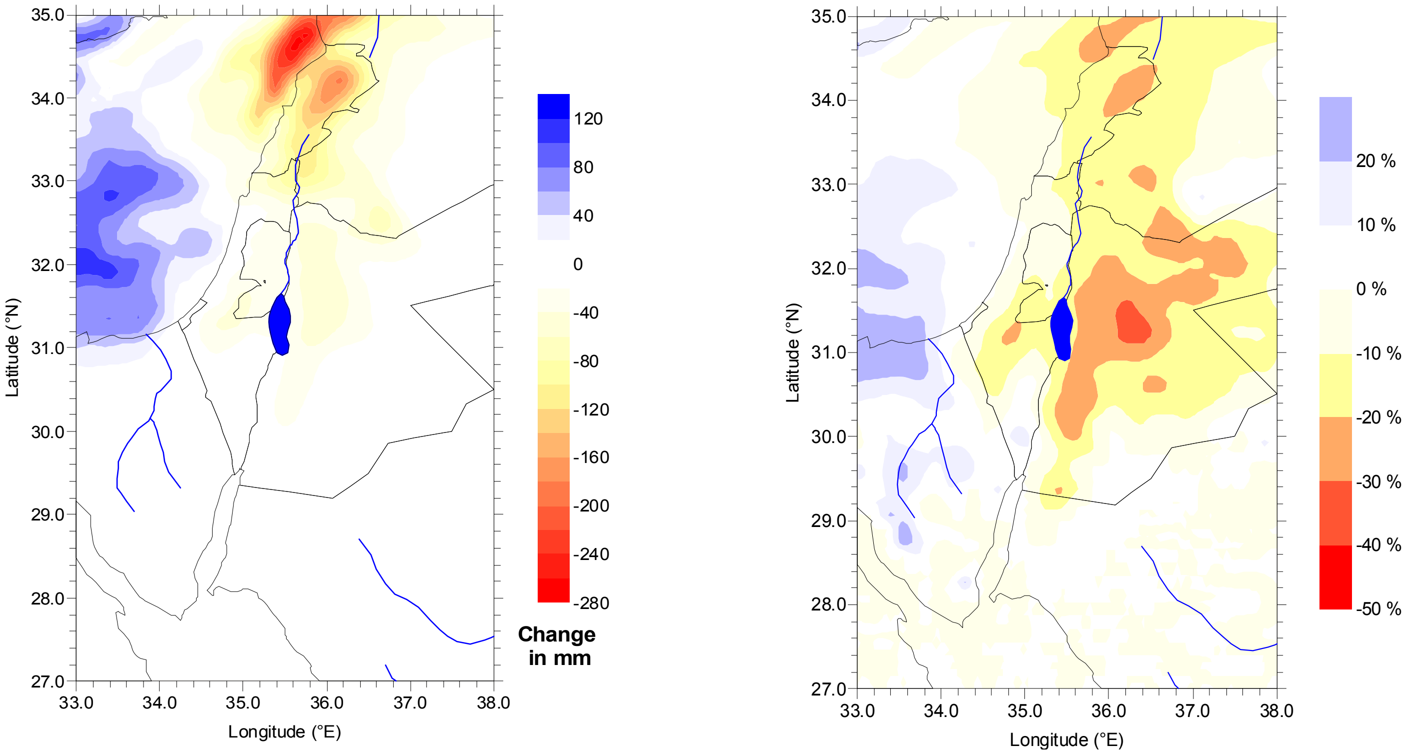
What are the expected changes in temperature?





Regional Climate Change & Water Availability EM/ME

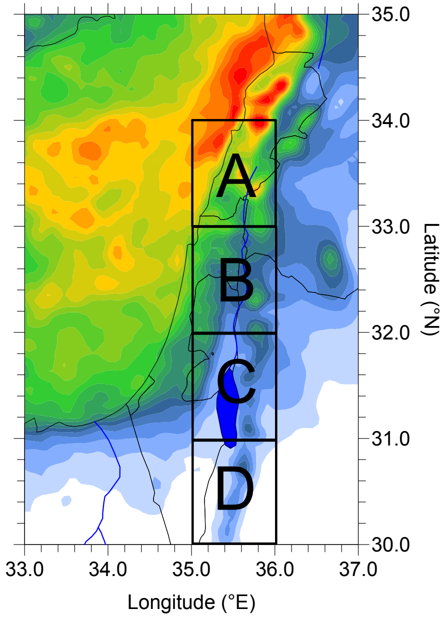
What are the expected changes in precipitation?

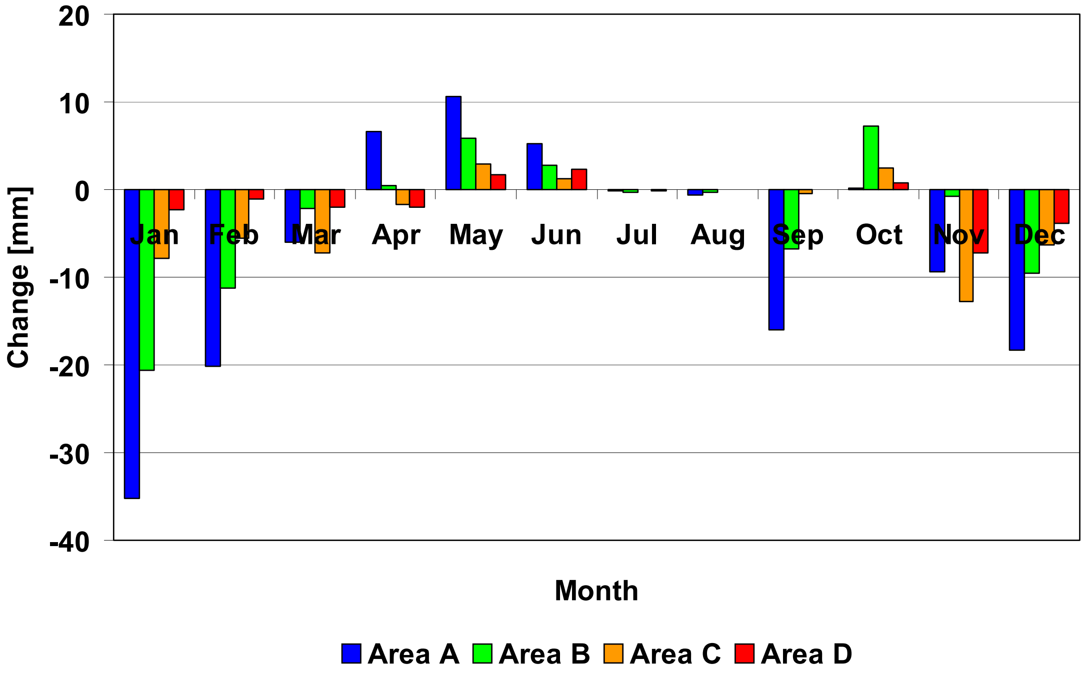


ECHAM4 & MM5, 18 km, B2, 2070-2099 vs 1961-1990

Regional Climate Change & Water Availability EM/ME

How does seasonal precipitation change depend on the region?



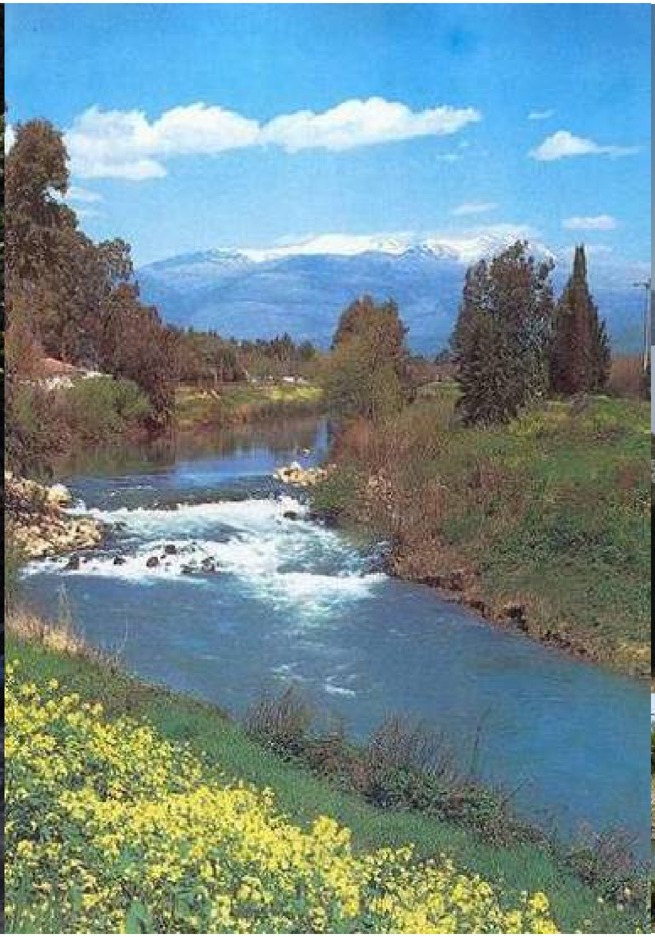


For all subregions: Decreased winter, increased spring precipitation

Regional Climate Change EM/ME

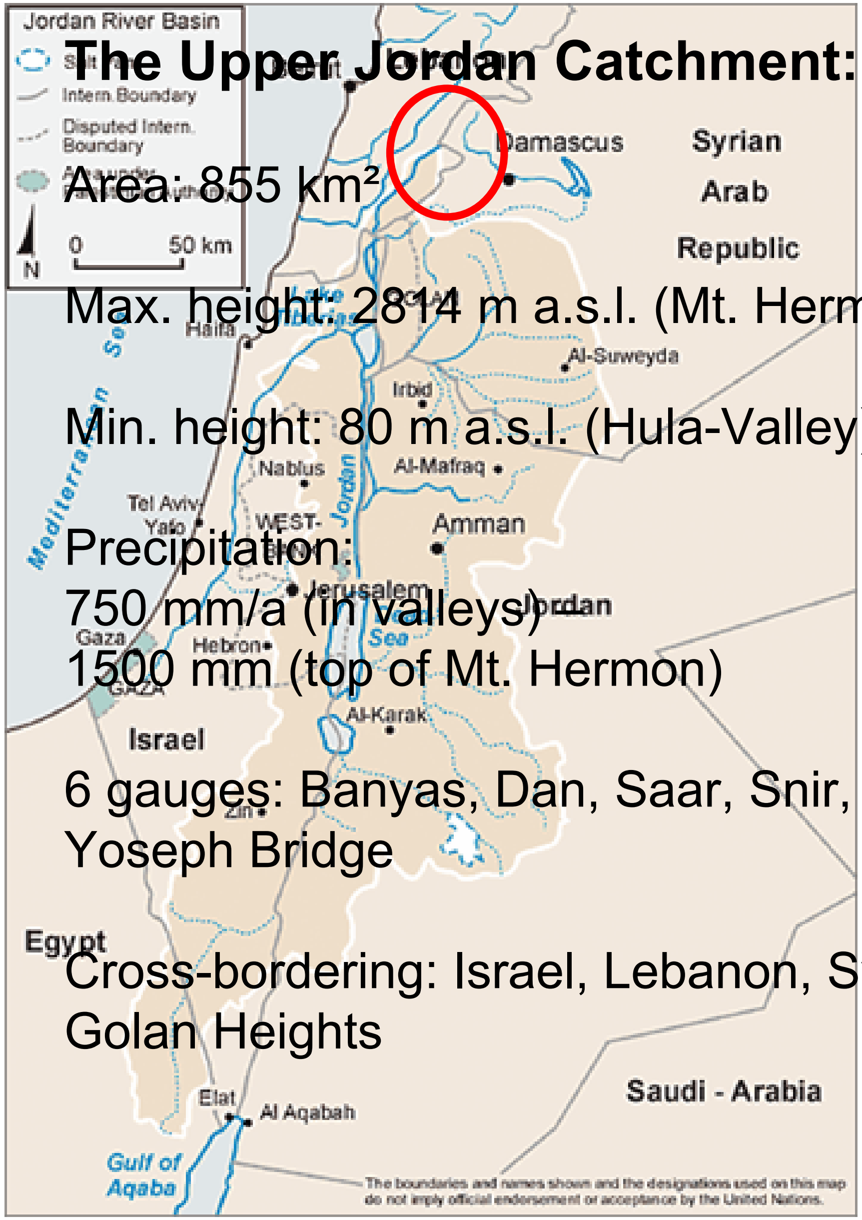
The Upper Jordan River Catchment

Banyas



Jordan & Mount Hermon

Regional Climate Change & Water Availability EM/ME



The Upper Jordan Catchment:

Area: 855 km²

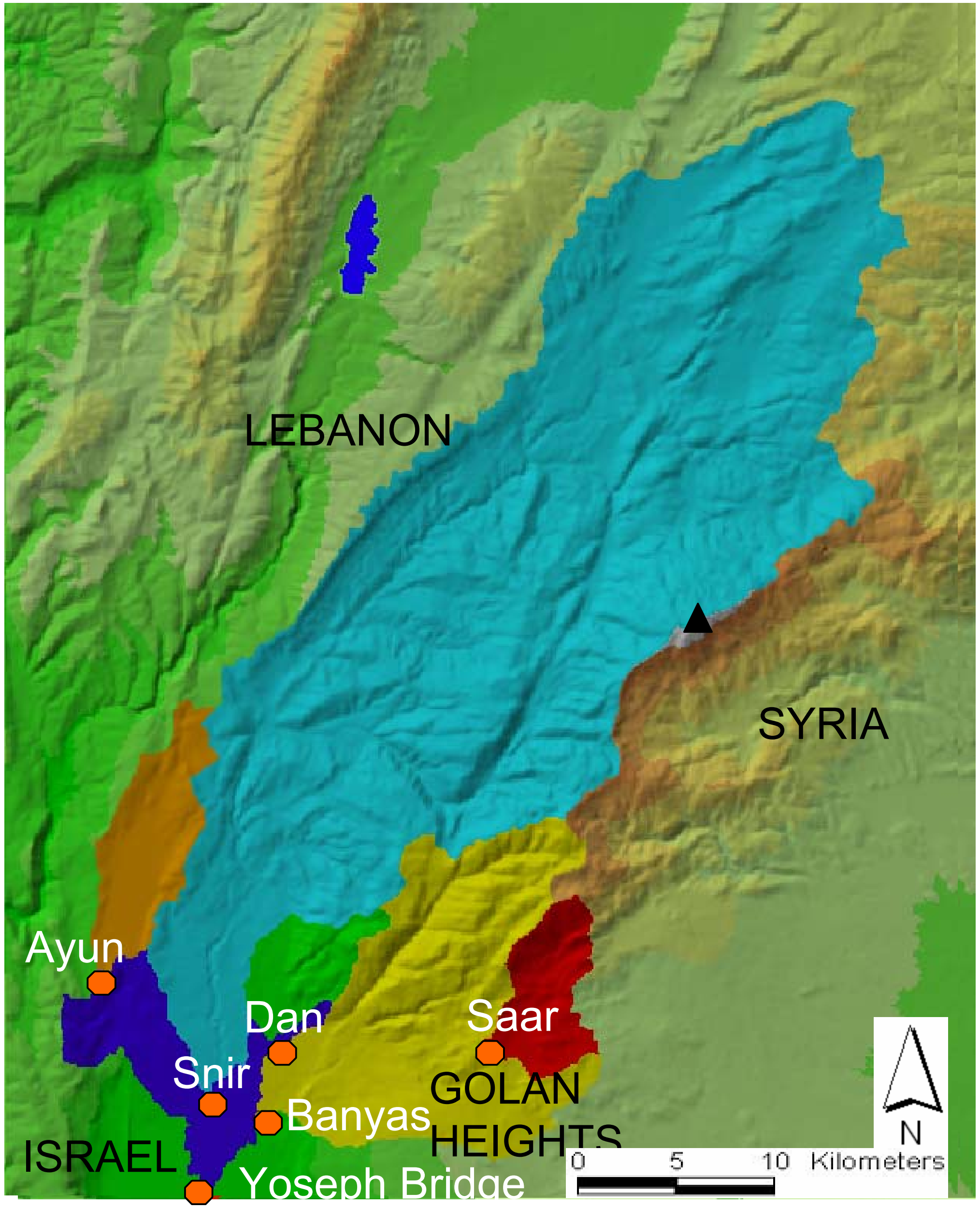
Max. height: 2814 m a.s.l. (Mt. Hermon)

Min. height: 80 m a.s.l. (Hula-Valley)

Precipitation:
750 mm/a (in valleys)
1500 mm (top of Mt. Hermon)

6 gauges: Banyas, Dan, Saar, Snir, Ayun, Yoseph Bridge

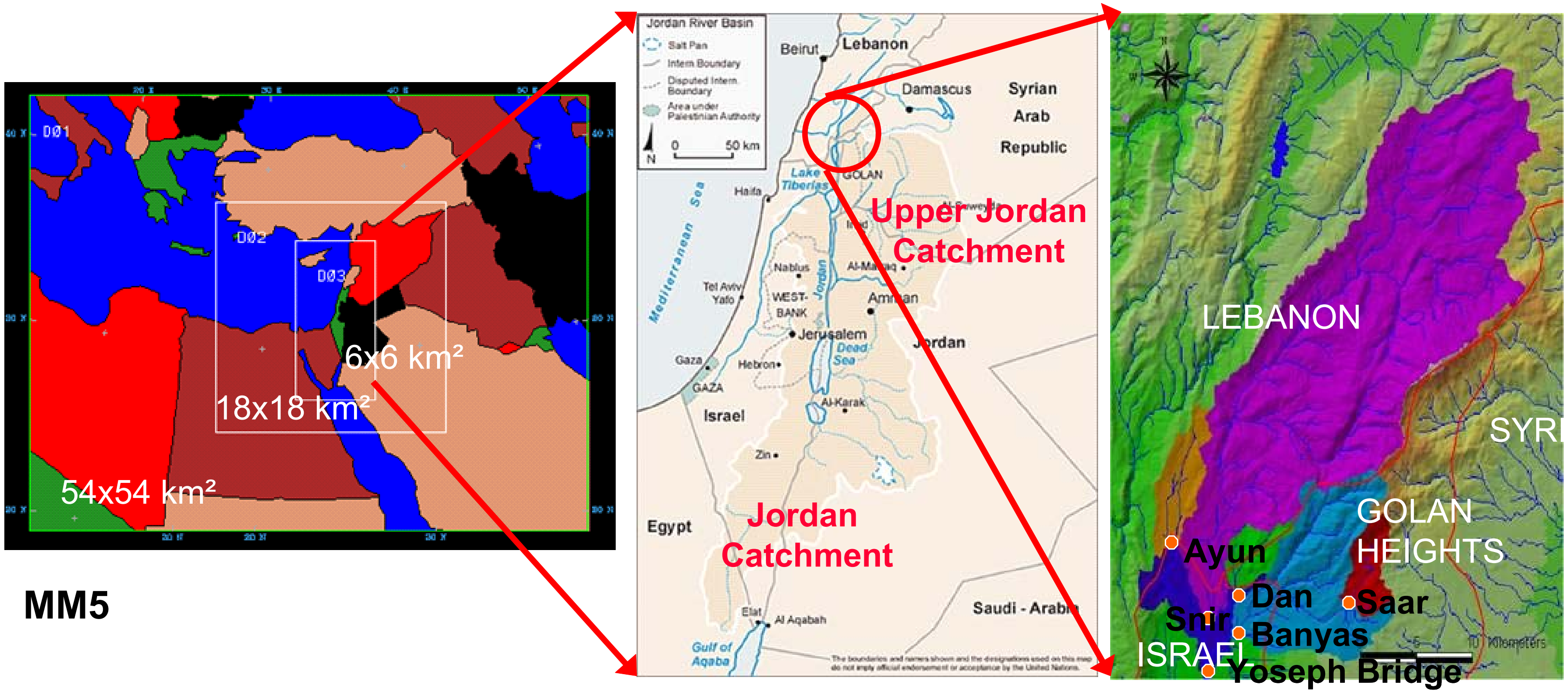
Cross-bordering: Israel, Lebanon, Syria, Golan Heights



Regional Climate Change & Water Availability EM/ME

Example of joint climate-hydrology simulation for hydrological impact analysis

Eastern Mediterranean/Near East (**EM/NE**) & Upper Jordan River Catchment



MM5

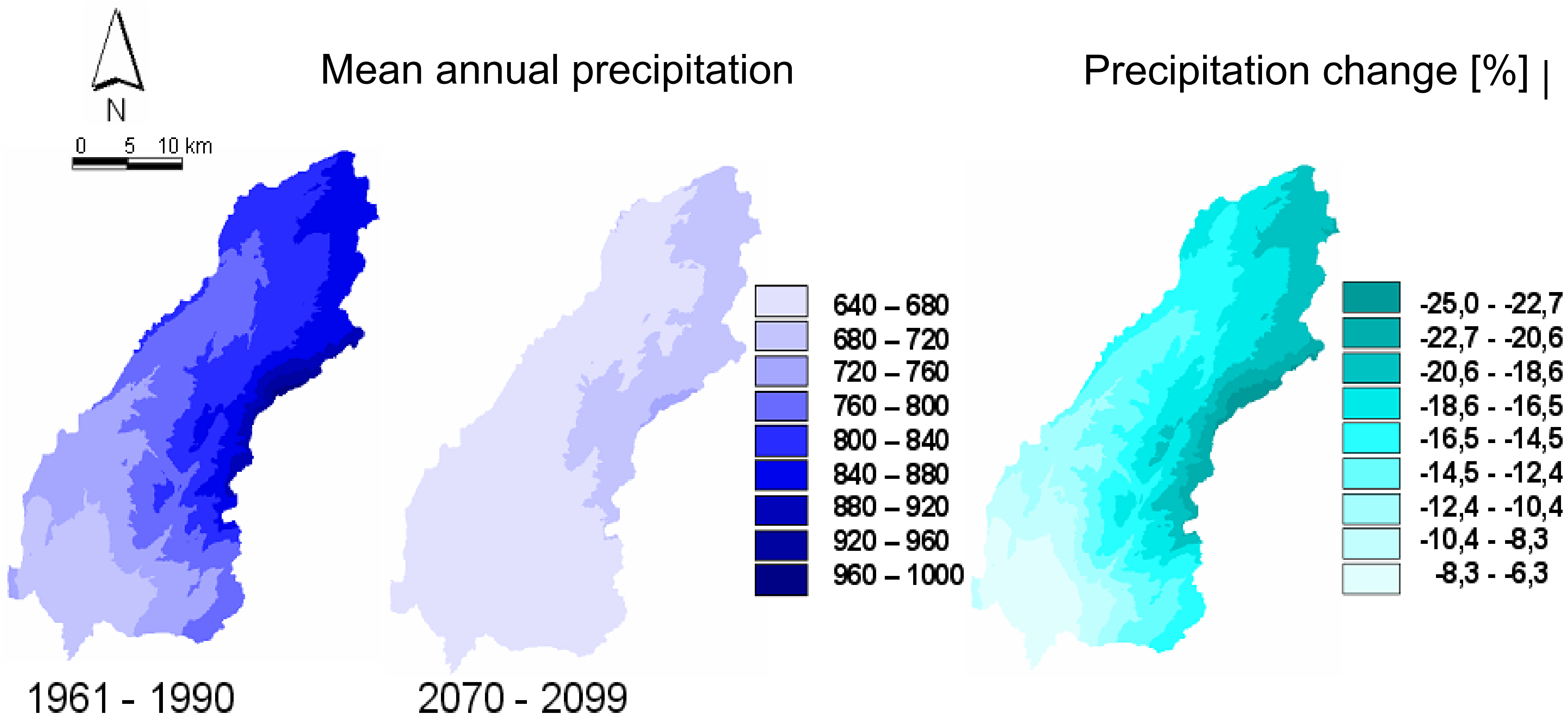
WaSiM

High resolution dynamical downscaling of global climate scenarios

Distributed hydrological modeling of surface and subsurface water balance in 90 m resolution

Regional Climate Change & Water Availability EM/ME

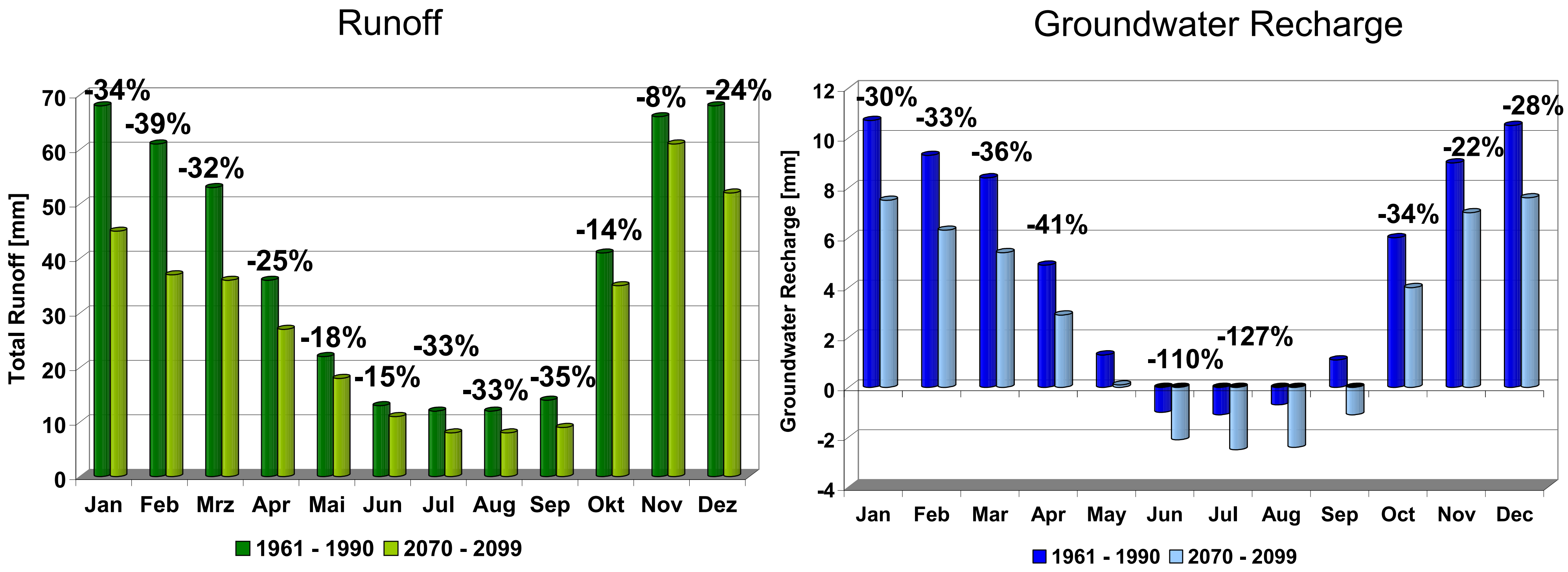
Joint climate-hydrology simulation for hydrological impact analysis



Upper Jordan River catchment

Regional Climate Change & Water Availability EM/ME

Joint climate-hydrology simulation for hydrological impact analysis



Runoff

Groundwater Recharge

Upper Jordan River Catchment

Significantly reduced water availability till 2100

Summary

Water and Climate – A Civil Security Issue!

- Water in sufficient quantity and quality is essential for all life and human wealth

- Severe water shortages expected due to population increase in many regions worldwide

- Global warming and climate change additionally alter regional water availability

- Increase of hydrometeorological extreme events expected: both floods AND droughts

- Climate science and hydrological research
  1) provide long term projections on water availability and flooding risks
  2) develop decision support systems for scientifically sound information
  3) support the design of adaptation strategies and assist in developing mitigation measures.

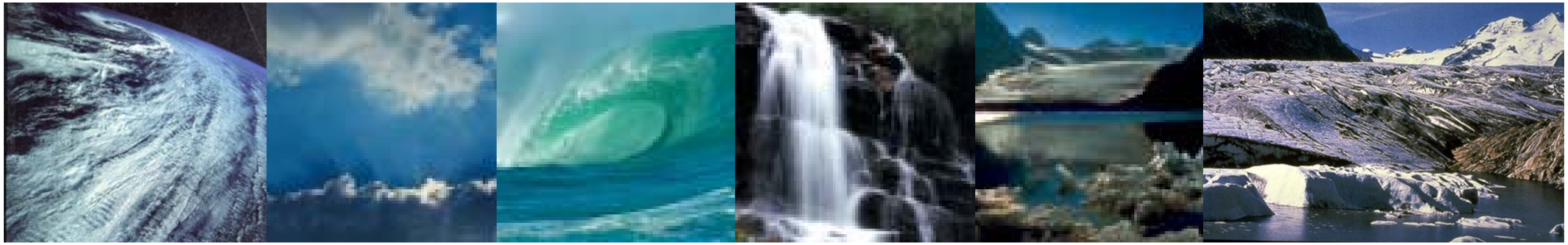
Thank you

for your attention

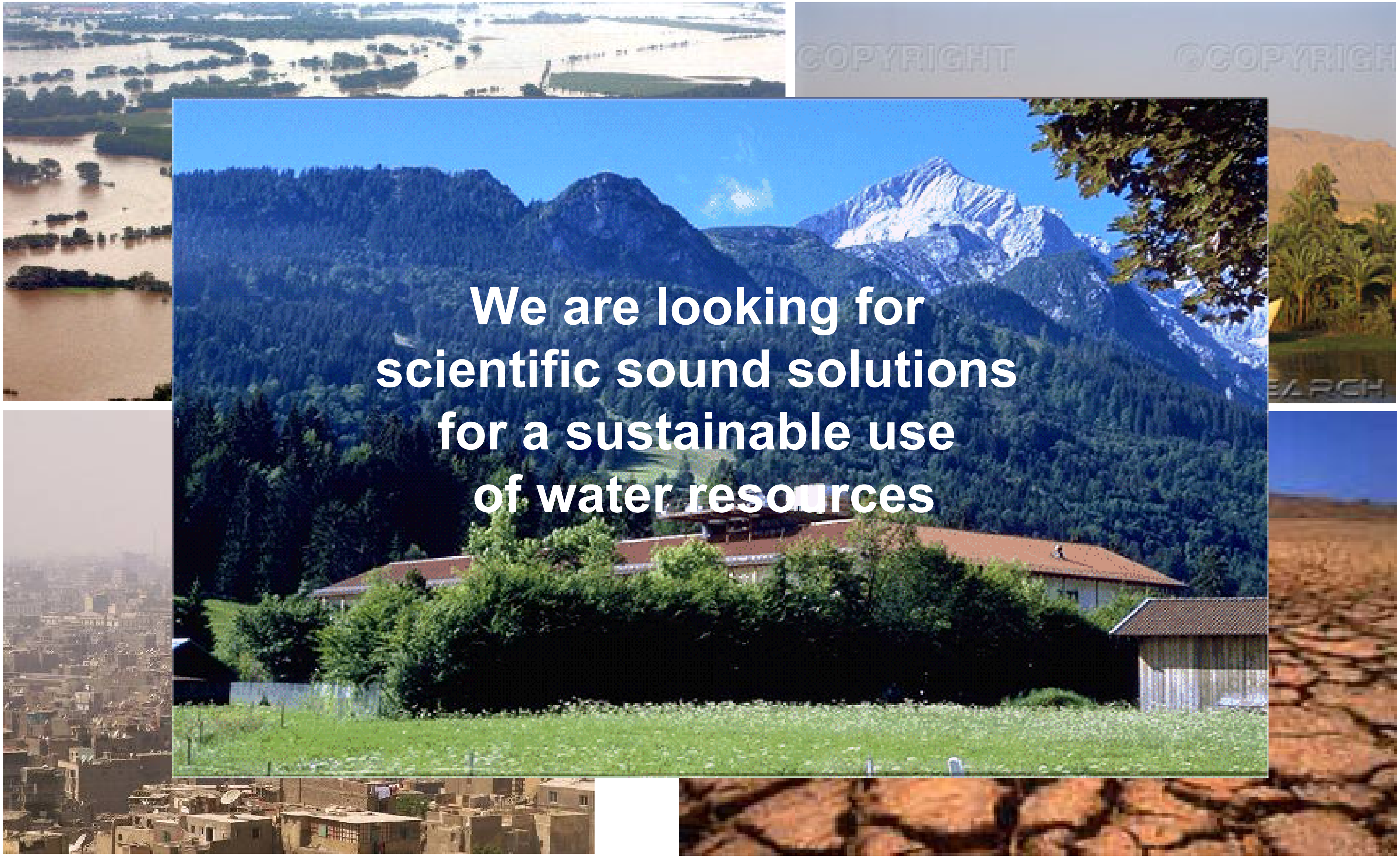
Climate and Water

Water in the Climate System

- Water in atmosphere: only 0.001% of total accessible total water on earth
- Water mass fraction in atmosphere: only 0.025%
  but tremendous significance as greenhouse gas:
  absorbs and emits effectively in infrared part of radiation spectrum
  contribution to natural greenhouse gas effect (-15°C → +18°C): 20.6°C
  (troposphere)
- Time scale from evaporation to rainfall: ≈ 8 days
  ⇒ fast atmospheric water cycle is link to slow reacting reservoirs ocean and ice



Research at IMK-IFU



We are looking for scientific sound solutions for a sustainable use of water resources